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IDA PAPER P-3046

# INFRARED SYSTEM PERFORMANCE, ATMOSPHERIC TRANSMISSION, AND MODELING ERRORS

Lucien M. Biberman

March 1996



*Prepared for*
Defense Advanced Research Projects Agency



IDA

INSTITUTE FOR DEFENSE ANALYSES
1801 N. Beauregard Street, Alexandria, Virginia 22311-1772



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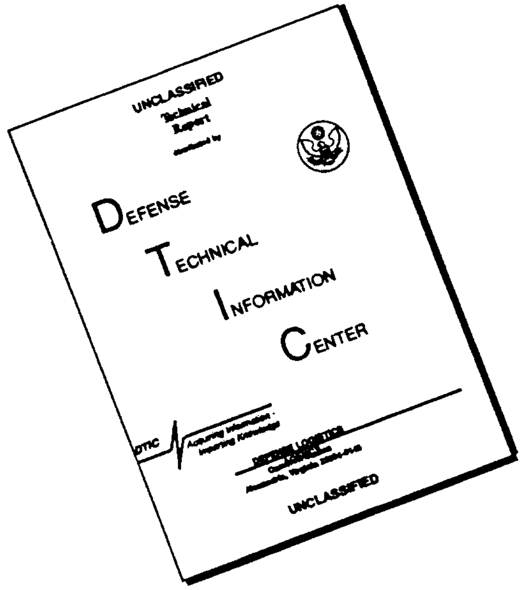


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INSTITUTE FOR DEFENSE ANALYSES

Contract DASW01 94 C 0054

DARPA Assignment A-180

# PREFACE

This paper documents work done for the Defense Advanced Research Projects Agency under a task on Infrared Clutter Characterization and Modeling. The report is a distillation of many inputs and contributions. The early drafts were reviewed and revised after many conversations with Jeffrey Nicoll and Penrose Albright of IDA, Douglas Crowder of NSWC, White Oak, and Robert Sendall whose detailed and informed comments were of great value.

The primary sources of data from the measurement programs of the early 1970's were:

- Terry Battalino who had the foresight to save the more important records from the Navy Optical Signatures Program (OSP) as PC files, all the other more complete tapes becoming obsolete as tape drives were updated and extended to a point where no available drives exist to read the original tapes.
- Gary Trusty of NRL who supplied much information concerning the San Nicolas and Cape Canaveral measurements of 1977.
- Ken Hepfer of NSWC, Dahlgren, who supplied the records of two major data collections for nearly worldwide meteorology in regions of blue water and littoral areas of interest to the Navy.
- Douglas Jensen of NOSC who provided the recent data collected near San Diego, CA.

The signatures of airborne targets in several bands of interest were computed by Elizabeth Ayers of IDA. The extensive processing of the data and preparation of the innumerable plots, and the final reformatting and concentrating that data were accomplished by Susan Taylor of IDA. The extensive library search effort into old data and records was carried out by Bettye Schubert of IDA. Finally, I should like to thank Dr. Gerrit de Leeuw of the TNO, Netherlands, for his penetrating review that led to the major restructuring of this document.

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# SUMMARY

## BACKGROUND

This report is in support of an effort being sponsored by the Defense Advanced Research Projects Agency (DARPA) and the Office of Naval Research (ONR) to provide a sound foundation for related development decisions concerning the choice of parameters for sensors like FLIR and IRST. The data in this report show the effects of weather statistics on measurements taken at one location over a period of time, at various maritime locations worldwide, and on smaller data collections made at other locations.

## PURPOSE

The armed forces long ago learned that the performance of guns, bombs, and missiles are best described using a Circular Error of Probability (CEP) to give some idea of the expected spread in performance accuracy. To the best of our knowledge no similar concept has been applied to sensors. In light of that, this paper will examine the statistics of atmospheric transmission and determine how important they might be in formulating a factor of merit for a given sensor, in a location and at an aspect, at a level of operation, and at a particular time such as a season or time of day.

The managers of development programs and service personnel, as users, have a serious need for development of a probabilistic concept of sensor performance. That is, how it will perform under foreseeable field conditions and how frequently it may be expected to operate successfully as a function of geography, weather, target type, and range. Force commanders must have realistic expectations of the performance of the weapons on which their very lives may depend. They know, from CEP data, what their guns will allow them to do against the targets they face—providing they know what the performance of their sensors will or might be.

## SCOPE

This paper examines the effects of atmosphere and targets on infrared system performance. The probability of the atmospheric transmission being less than a required

value at a given range (thus resulting in failure to acquire a target) is one indicator that will be needed in such a CEP-like metric. For any particular system an overall statistical performance metric should include the spread of the effects of the principal variables affecting the performance range of the system being investigated.

Intuitively, it would appear that for an IRST searching for low altitude targets the atmospheric effects and background characteristics would be expected to dominate system performance calculations and, indeed, actual performance. A series of calculations based upon the variability of the atmosphere, the relative detector characteristics, and the signatures of a variety of targets show that often the ***character of the targets*** dominates choice of optimum spectral band. The presence or absence of plume emissions and speed of the target can often change the preconceived notion of what is the best band.

Imaging systems presently are apt to be used to acquire *surface* targets, in which case the atmospheric variability is usually the dominant factor. Thus, an understanding of relative and absolute humidity statistics in the region of interest and the season and time of day of interest are the factors that tend to dominate.

The basic data for creating a performance estimate depends on four fundamental phenomena that must be understood before defining and designing the next generation IRST:

- The characteristics of the targets
- The characteristics of the backgrounds
- The transmission of the atmosphere
- The characteristics of the sensor.

However, traditional engineering calculations are based on highly detailed data concerning the sensor and very little on the character of the target, the background, and the weather and atmosphere.

Atmospheric transmission is often simply taken as a mean value defined by season, geographic location, and altitude. This approach has been a source of concern to the writer. Previous studies at IDA, largely by Robert E. Roberts, have shown that the atmospheric aerosols and *not* the mixed atmospheric gasses are often the most important factors limiting the use of infrared sensors near sea level. Further, IDA studies based upon data obtained at Hannover and Grafenwöhr, Germany, in extensive trials in the 1970's, have clearly shown that the atmospheric transmission is often best defined as quite good or

very bad, with a minority of cases in which the transmission of the atmosphere exhibits an "average between the good and bad."

## DATA

Presently there is a desire to find a single set of the atmosphere and sensor parameters to be used in the design of an IR system that will fill the Navy's need at any geographic location of interest for Navy warships. Here we examine the wide variation in atmospheric transmission from the limited amount of data that are accessible, at least as far as we could determine, to address the Navy's needs. We have used the following principal sources: a collection of atmospheric transmission data ***computed*** from weather conditions at marine and littoral locations put together by Hepfer of NSWC, Dahlgren; a small but detailed measured collection of data by NRL at San Nicolas Island in the Santa Barbara Island group, over a period of less than a month; an excellent collection of both measured and calculated data from San Nicolas Island by Terry E. Battalino at NAWCWPNS, Pt. Mugu, CA; measurements by NRL at Cape Canaveral; and measurements by NOSC at San Diego, CA.

The Dahlgren data compilation computed the transmission from weather data at shipboard and other data collection points, but had too limited a number of samples from any single location to show in detail the temporal variation—the time spans over which drastic shifts in atmospheric transmission occurred. The selected weather data records were entered into a "Navy Aerosol Model" designed initially by the late Barry Katz of NSWC, White Oak, and continuously updated since, recent work being done by Dr. Stuart Gathman at NCCOSC.

The NRL data of San Nicolas Island shows frequent changes in aerosols and forms the basis for an important part of this study.

The Battalino collection (see Appendix B) shows the recorded and modeled data for the high-level activity periods at San Nicolas Island in 1978, 1979, and 1980. Unfortunately, in places other than San Nicolas Island we must use modeled data since that is all that may be available.

Most of the models are based in large part on LOWTRAN and, within LOWTRAN, a series of aerosol models based upon meteorological data. The modeled data seems to fit rather well in the 3–5 region and not as well in the 8–10 band.

The data analysis on about half of the rest of the data is still in Battalino's hands. Thus, we are able to look at data from 1978 and 1979 and await further work at Pt. Mugu.

## CAVEATS

It must be strongly noted that the collection of data available included *only* low altitude horizontal path data. We have been unable to locate any significant number of measurements that allow slant path or vertical path predictions.

These data therefore must not be used for estimating any but quite low altitude performance of IR devices for point detection and tracking or for imaging. Until a serious effort is made to accumulate such vertical or slant path data on system performance with surface based sensors and airborne targets at flight altitudes of interest, the predicted performance over many latitudes and seasons will be based on opinion, not fact.

## FINDINGS

From our limited data base of *measured* data in the 3–5 and 8–10 micron bands, we find atmospheric transmission in the 3–5 micron region is better most of the time. However, when aerosols are quite dense (which may be as much as 10 percent of the time) the 8–10 micron region is superior, though the transmission may be so low in some cases that few long-range IR operations at low altitude are feasible in any band.

The simplest way to summarize the comparison between the midwave and longwave data is to consider the distribution of transmission for the two bands. The longwave data can be described with a relatively broad gaussian distribution with a mediocre mean value for transmission. Variations in the aerosol content of the atmosphere have less effect on the overall distribution of transmission in the 8–10 band than in the 3–5 band. The midwave data, on the other hand, is double-humped. On low aerosol days, it is described by a relatively narrow gaussian distribution that is clearly higher than the longwave distribution: midwave is clearly superior. On higher aerosol days, the midwave transmissions form another narrow gaussian distribution, but lower than the longwave distribution: the longwave is superior. The value of the transmission averaged over all days for the two bands are comparable and meaningless. Just as in the Grafenwöhr tests, there are good days for the midwave and bad days for the midwave. The crucial question is "What is the distribution of the good and bad days?"

The question of distribution can be answered in the analyzed databases that may be taken as representative of a particular geographic area and season covered. However, we

believe the frequency of high aerosol extinctions ***may*** be more of a problem in the cold latitudes. We suspect that for the Navy the diurnal variation in relative humidity may be greater in the cold latitudes than in the warmer regions. We have statistically insufficient data at our disposal to relate atmospheric transmission to weather at any place except San Nicolas Island.[1]

Probably the most important result of this ongoing study concerns the wide variation of atmospheric transmission caused by the wide variation in weather. Clearly, the serious limitations by aerosols are drastic but seem to occur, at least in open oceans or in littoral locations, less than about 10 percent of the time for the data from each of the sources we have examined. This may be true or may well be that transmissions, or related parameters about aerosols, were not collected when the aerosol's concentration and sizes were too severe for measurement.

To achieve a better understanding of the atmospheric variability and its effect on the design and use of optical and infrared instruments and systems, one must either gain access to the great volume of data previously recorded but now apparently lost, make more measurements, or base choice of parameters on personal opinions.

Finally, we note that just as one changes lubricating oil when tank engines are taken from the Arctic Circle to the Equator and issues new clothing to the troops that accompany such equipment, we must also realize that optimum parameters for sensors will change as the operating environment changes (i.e., from the Bay of Fundy to the Gulf of Mexico). The question becomes "What is the differential performance between the two most popular spectral pass bands and how much is to be gained by including more than one band in a yet-to-be-built system?"

Perhaps an anecdote is appropriate at this point. Though we do not have the details, or any real confirmation, the decision of a helicopter-ferry firm servicing offshore drilling platforms is interesting and pertinent. The impact of weather on the ability to land on platforms in low visibility conditions, even with long wavelength FLIRs, has been adverse and thus expensive. The firm decided to underwrite the use of ***dual bands,*** to insure the ability to find the landing pad under ***either*** high absolute ***or*** high relative

---

1 We speculate that data collection ceased when the transmission was very low in really bad weather since the transmissometers could not see through the selected path length when aerosols were thick. Thus, there is a possibility that a bias exists in the data from San Nicolas Island with fewer measurements taken when the weather was bad (and, presumably, both bands would have been disabled). There is also the question whether the aerosols reflect, too much, the effect of breaking surf nearby.

humidity. The decision was made after comparing the costs of the many flights unable to complete missions versus the cost of somewhat more complex and more expensive sensors.

## CONCLUSIONS

In summary:

1. Probably our most important conclusion is the following: Since the performance of passive infrared systems varies roughly with the atmospheric transmission of the path, all else being equal, it can be seen that weather is a major driver in the performance of such systems. Thus, we show that performance is tightly related to the local conditions, and thus to the season and location of operation.
2. Further, we show that for performance ***there is no single value; rather, performance is best shown as a broad probabilistic roughly bell-shaped curve for any one location and season.***
3. If we consider sensor performance to be given by a gaussian distribution, (i.e., the center point is located for any one target at a range determined by sensor parameters and perhaps the gross meteorological conditions, while the spread in the bell curve is related to the environmental variations), then the important question is how to define the center and spread of that distribution.
4. In the case of the Army, prior experience with the various antecedents of the common module FLIR showed that the longer wavelengths were more effective than the 3–5 FLIRs of that period. Thus, the 8–10 band was adopted for the recent generation of focal plane array FLIRs. What is not established is the range at which such FLIRs will perform against a variety of ground based near ambient targets in a wide variety of geographic locations, seasons, and atmospheres. Some advocate a return to the 3–5 band, but there really is little data or evidence that this is the best worldwide and for all seasons. We thus raise the question of dual bands (see Section VI).
5. In the case of the Navy, a maritime environment and a wide array of targets from the very hot to near ambient creates a real problem in choice of band. In the case of San Nicolas Island alone the overall spread was more than three-to-one in transmission, but with a complicated structure.

Since the character of the atmosphere changes dramatically (e.g., where we have made comparative observations against surface shipping, from the coast of Maine to the coast of Texas), a mobile, quick-response Navy needs dual bands to cover such changes in environment for surface-to-surface tasks, but probably needs only the 3–5 micron band for self-defense against most attacking air threats.

# I. INTRODUCTION

The design of new high performance infrared (IR) equipment is constrained by four major factors: the spectral characteristics of the assorted targets and backgrounds to be faced; the spectral transmission of the atmosphere; the spectral response of the available detectors; and the algorithms used.

Traditionally, engineering calculations are based on rather detailed data on the spectral character of the target and that of the detector. The transmission of the atmosphere is often taken as a mean value defined by the season, geographic location, and altitude.

Today the Navy is again very serious about the design of a new Infrared Search and Track (IRST) system for both surface and airborne elements of its fleet. There is currently a desire to find a single set of the atmosphere and detector parameters that will do a more than adequate job at any geographic location of interest to Naval warships. IDA was asked to examine the choice of design parameters, and thus needed to examine the data of several atmospheric transmission programs, each of which lasted up to 3 years. In response to the Navy's request, our plan was to examine maritime locations; there was little reason to examine other locations such as the Sahara or the steppes of central Asia.

This preliminary paper attempts to examine the overall variation in atmospheric transmission worldwide and the detailed variation at a single location over a period of 3 or more years; it attempts to relate the available data to the causes that give rise to that variation.

Our main difficulty in pursuing this study was an inability to locate the data resulting from a series of data collection programs that we estimated to have occupied a large number of people over much of the 1970's, possibly representing as much as 100 man years of effort.

Our most important conclusion may be stated as follows:

*Since the performance of most infrared systems varies roughly with the atmospheric transmission of the path, all else being equal, it can be seen that weather is a major driver in the performance of such systems. Thus, as we shall show later, the performance is tightly related to the local conditions, and thus the season and location of operation.*

Further, we shall show there is no single meaningful value for IR system performance, rather that probable performance is a broad roughly bell-shaped curve for any one location and season.

# II. SOURCES OF DATA

In the early 1970's a group of advisors to DDR&E/OSD saw the need for a series of basic programs supporting the infant technology of infrared in search applications. One of the chief unknowns was the variation in the absolute effects of weather. As a result, in 1977 a series of programs were begun in all three Services.

The Navy set up the Optical Signatures Program (OSP) at San Nicolas Island, the Army set up a major program at Grafenwöhr, Germany, and the Air Force instituted a NATO program named Opaque. Each of those programs published a brief summary of what was learned.

After trying for several months to find the original data from these programs, we contacted the office of Jon Wunderlicht, who was the Program Manager for the Navy's OSP program. We learned, unfortunately, that he was no longer living and found that no one had the slightest idea of what we were talking about or asking for. We then contacted Lowell Wilkens who was formerly associated with Mr. Wunderlicht. Lowell Wilkens then phoned Terry Battalino, who wrote and sent me a significant amount of that data.

Not only had Battalino apparently foreseen the trouble with the older tapes and the obsolescence of the tape drives that might read the tapes, but he apparently arranged to copy the most important data. All our attempts to find either the old tapes or drives that might read them resulted in the manufacturers of such equipment referring me to computer junkyards, which had no such equipment.

Battalino not only saved the data but did a beautiful analysis of the original measured data and the models that are purported to predict that data. Battalino has apparently done this analysis for about half of the data he has. From all the above, it seems clear to me that the results of nearly 100 man years of important work, conducted by all three U.S. Service laboratories and several international NATO activities, only Battalino's work and two shorter detailed NRL analyses of perhaps 20 days' measurements remain as viable inputs for any related future applications.

Similarly, we have obtained quite recent data from Douglas Jensen of NOSC.

Ken Hepfer of NSWC, Dahlgren, has collected data from a large collection of weather stations, mostly at sea or in littoral regions. Using such data he employed a variety of models to calculate the transmission at these locations. Unfortunately, though he has collected many samples from many places, there is not enough at any one place sampled frequently enough to give an insight about the variations from day to night and season to season, or variations within a season.

With the exception of the data noted above, we have no other measured calibrated raw data from which to examine the broad performance of infrared sensors. All other data are modeled or theoretically derived from a variety of inputs, but we have been unable to uncover the mass of data collected in the late seventies at the expense of perhaps 100 man years of effort.

Thus, we have been forced to base a large portion of our work on the collections at San Nicolas Island, though it is believed by some that breaking surf around the island together with some wind patterns could give a bias to that data.

# III. THE EFFECTS OF HUMIDITY

It should be noted that humidity must be considered carefully. If it is relative humidity, then high values tend to favor the formation of hydro-aerosols and thus strongly reduce transmission in the 3–5 micron band transmissions. On the other hand, high absolute humidity together with relatively low relative humidity can occur in warm weather regions such as the Gulf of Mexico off the Texas coast. Such a condition, if without high winds and breaking seas, does not necessarily favor aerosol formation. Thus, one may well find good transmission due to the minimal absorption and little aerosol induced scatter in the 3–5 micron band, yet poor transmission due to high absorption by the water vapor continuum in the 8–10 micron band. Clearly the optimum choice of bands, at least with respect to atmospheric transmission, is affected by these two dominant factors.

Further, it should be noted that the rise and decay of aerosols can occur in a time span of hours while the absolute humidity tends to come and go as air masses enter and exit the region of interest. Such time constants are more likely to be in terms of several or more days. Some variations in aerosol content are periodic and are often termed morning fogs. For example, over Hannover, Germany, fogs tend to build fairly consistently in the wee hours of the morning, and "burn off" by perhaps 10 a.m. achieving best transmission in early afternoon as shown in Figure 3-1. In this figure, based upon data presented in IDA Research Paper P-1123,[1] we show for a FLIR the relative probability of detection versus range of a vehicular target at ground level in central Germany for each of 24 hours starting at midnight. Clearly, dawn tends to be a poor time in which to expect good visibility or deploy optical sensors, yet in WWII air attacks often were scheduled for dawn.

Other important factors such as major changes in the character of the air mass may change suddenly, then last for days (e.g., within the United States the variations experienced in "tornado season," the arrival of a "nor'easter," or a broad low pressure area over mid-Atlantic coastal regions and the subsequent moisture laden air from the Gulf of Mexico). These are periodic and hard to forecast in longer range mission planning (i.e., the wait for weather in planning D-Day in WWII).

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1 IDA Paper P-1123, *Effect of Weather at Hannover Federal Republic of Germany on Performance of Electrooptical Imaging Systems: Part 1: Theory, Methodology and Data Base*, August 1976.

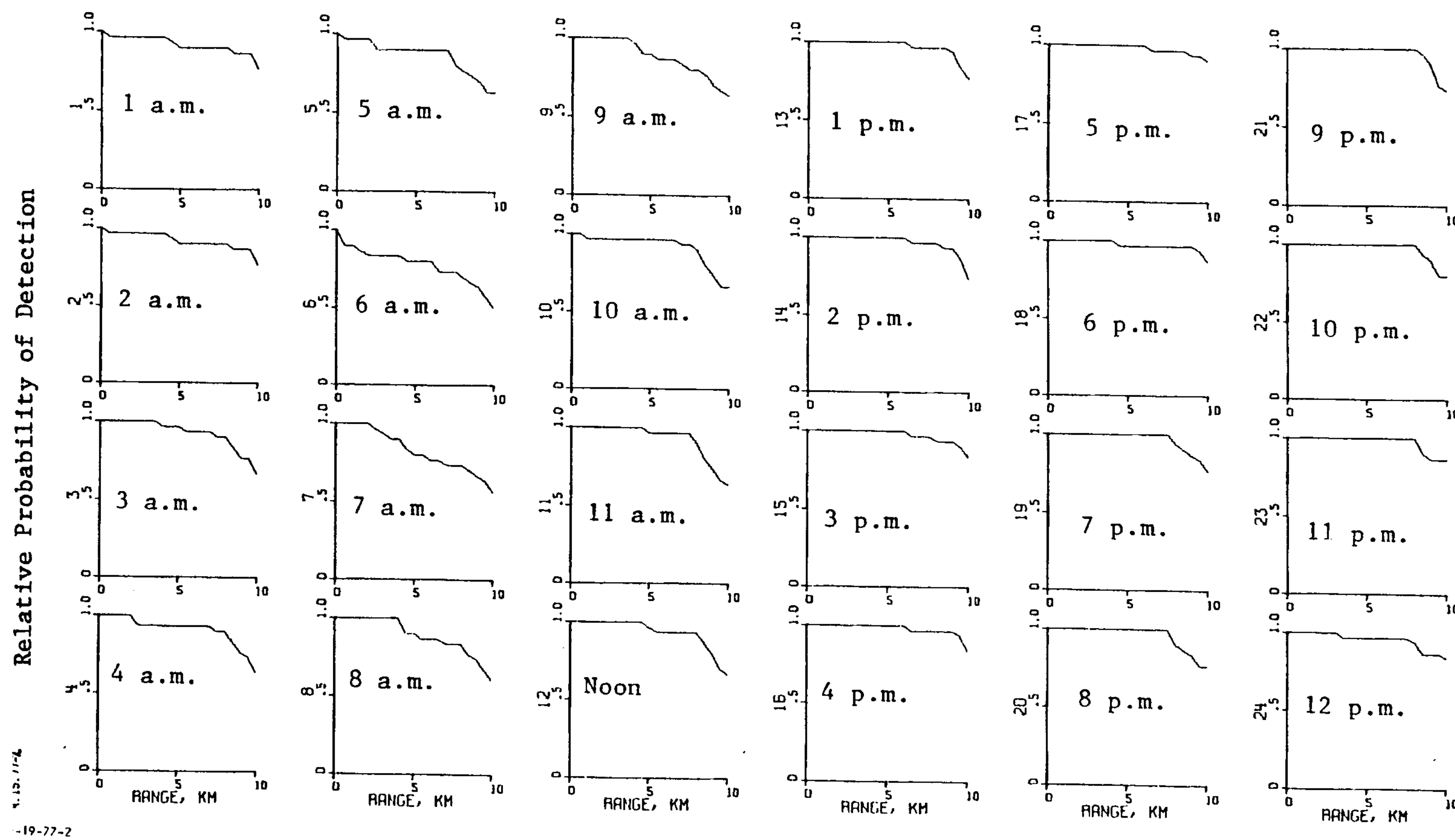


**Figure 3-1. Typical Probability of Detection vs. Range at Hourly Intervals, Central Germany**

# IV. THE IMPLICATIONS OF THE DATA

## A. INTRODUCTION TO THE DATA IN THIS SECTION

In this section we show a series of histograms for all the data collections for the conditions and ranges at which the measurements were made. Thus for the data at Cape Canaveral the distance between source and receiver along the over water path was 5.1 km, while the OSP data at San Nicolas Island was over a land mass near the edge of the Island for a path length of 4.067 km.

In this report we show plots of expected transmission over several path lengths by using the aerosol extinction coefficient deduced from the total measured transmission minus the calculated (from LOWTRAN) for the aerosol-free transmission or extinction at each of the ranges for which the data is shown, and the extinction coefficient/kilometer, which we took to be independent of range

In the case of the data taken at San Nicolas Island, we show the transmission histogram for the entire period of the NRL measurement program (about a month), while in the case of the Navy's Optical Signatures Program we show extinction and transmission histograms for two sets of approximately one years collection of data. In the case of the Cape Canaveral data, we show a transmission histogram for approximately one month's worth of data.

## B. NRL DATA AT SAN NICOLAS ISLAND

Two histograms of the measured data are shown below (Figure 4-1). The complete set of data and a discussion of that data appear in Appendix A. The data was taken from NRL Report 8618,[2] being the best source of statistics for short term temporal variation in extinction available to us at the time of preparing or printing this report.

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2 NRL Report 8618, *Results of Laser-Calibrated High-Resolution Transmission Measurements and Comparisons with Broad Band Transmission Data: San Nicolas Island, California, May 1979*, September 30, 1982.

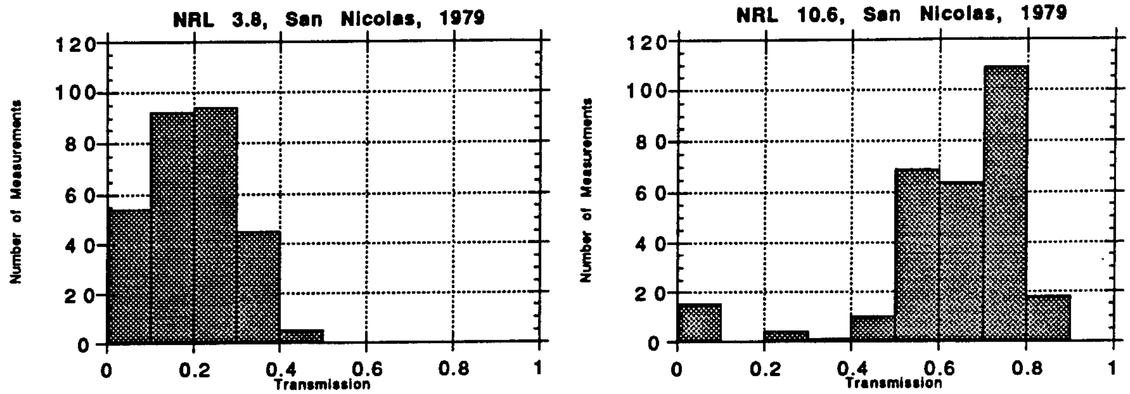


**Figure 4-1. NRL San Nicolas Data**

## C. THE OSP DATA AT SAN NICOLAS ISLAND

Battalino of Pt. Mugu had saved a portion of the total data taken under the OSP program. There may be other data available in unprocessed form, but the support to extract and analyze that data does not seem to be available.

It seems clear that the general form of the measured and modeled data match fairly well, but that the measured data are clearly much higher in absolute values of transmission than that predicted by the four models examined (Figures 4-2, 4-3, and 4-4).

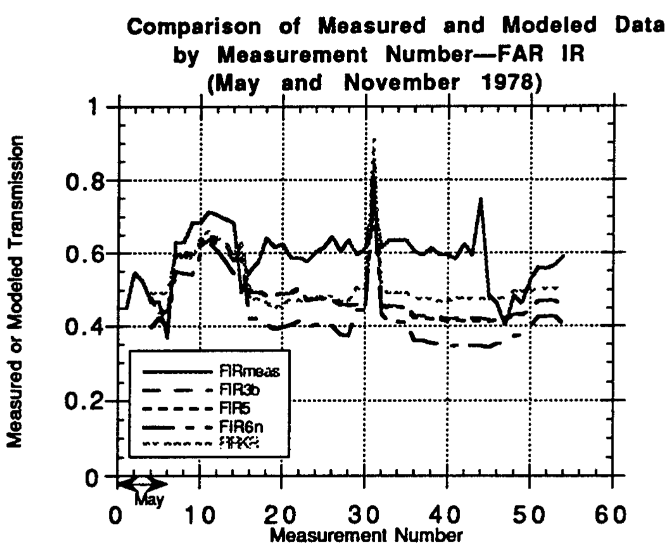


**Figure 4-2. The Battalino Data for San Nicolas Island**

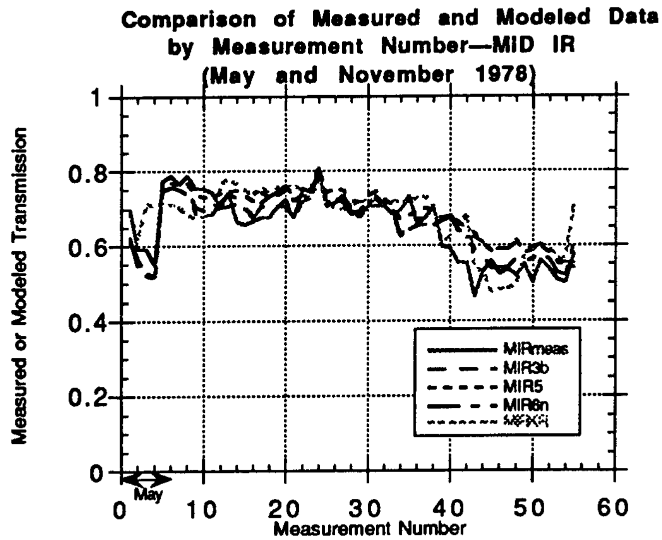


**Figure 4-3. Comparison of Data (May and November 1978)**

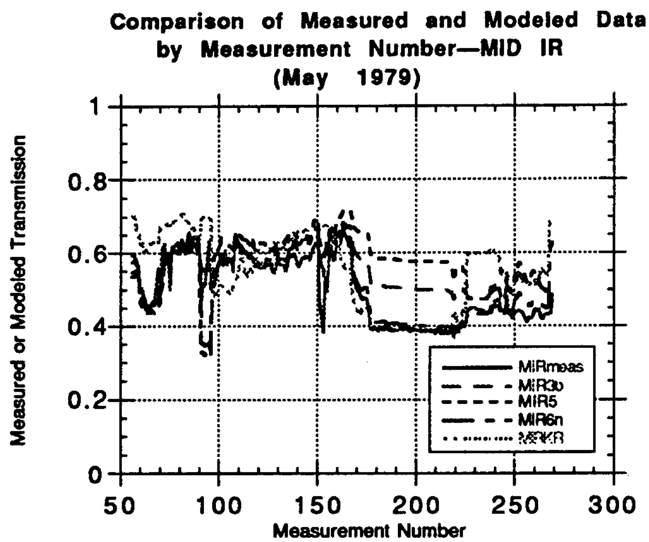


**Figure 4-4. Comparison of Data (May 1979)**

As yet we are unable to explain whether the radiometers were improperly calibrated, whether the models for the aerosol components are incorrect, or whether, as G. deLeeuw points out in private correspondence:

> This may occur in very clean air where the sub-micron fraction has less mass, i.e., the mass distribution peaks around 1 μm. In general I observe that the extinction from the UV to the NIR is fairly wavelength independent over sea, in clean maritime air.

The Battalino OSP data for the 3.73 to 3.9 micron band shows a considerably better match to the various models he used for comparison against measured data, than does the 8–10 band data.

The histograms shown below (Figure 4-5) are based on the data Battalino has been able to recover. The data from which these two histograms are plotted appears in the Appendix B for the OSP data.

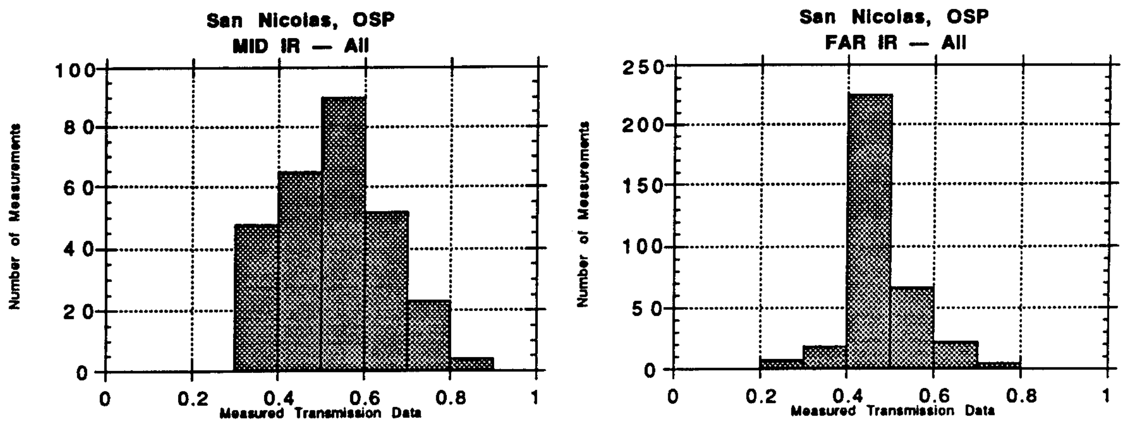


**Figure 4-5. OSP Measured Data, San Nicolas Island**

## D. THE HEPFER COMPUTED DATA COLLECTION

The histograms for the Hepfer data are taken from his collection and separated by 10 degree latitude bands, the duration and number of measurements being whatever number and duration occurred in that collection.

Our point is to show the spread in extinction or transmission rather than the absolute values, those being shown for each collection in the appropriate appendix. It is this spread in the transmission that so strongly affects the probability of a sensor to see an object at the longer ranges.

The collection of such data are shown in Appendix D for the Hepfer data; in Figure 4-6 we show only two of those histograms.

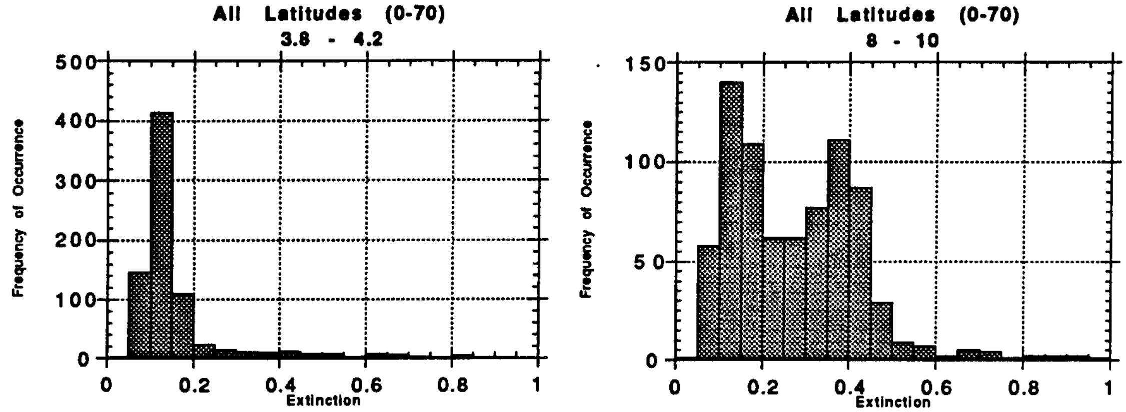


**Figure 4-6. Band Comparison Computed from Meteorological Data**

## E. THE NRL DATA FROM CAPE CANAVERAL

Figure 4-7 shows transmission data from Cape Canaveral taken with laser beams. One must be cautious about this data since this data was taken with a large number of laser lines in each of the two bands, and such lines may or may or may not show more or less transmission than the region between such lines. Often in high humidity, such as at Cape Canaveral, the short wavelengths are quite good but the long wavelengths may be mediocre to poor. One must be careful about this broad conclusion, since in a very cold, very clear, low humidity setting both bands are quite good.

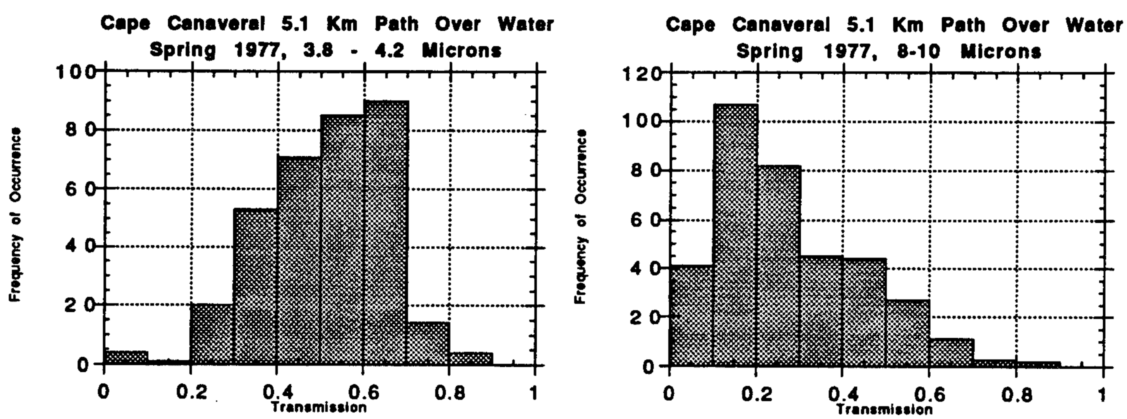


**Figure 4-7. Laser-Based Measured Data**

For a given place and time, the data must be sorted point by point to make a unequivocal statement without fear of contradiction, but it would appear that high absolute humidity is responsible for the poorer response of the long wavelength transmissions when the shorter wavelengths look so much better. This is inferred to occur because the effect of

absolute humidity has little effect on the transmission in the 3.8–4.2 micron band while the water vapor continuum severely limits the transmission in the 8–12 micron region.

On the other hand, when the relative humidity gets quite high, the formation of high concentrations of hydro-aerosols tend to grow rapidly and more seriously affect the transmission in the 3–5 micron band than in the 8–12 micron band.

It is hard from an examination of these histograms to say that either band is clearly ***universally*** superior in transmission. It does seem as if the times and places determine which band is the band of choice purely from a transmission viewpoint. Thus it becomes necessary to examine these results by taking the product of atmospheric transmission, target signature, and detector spectral response to determine in which band the product of these three important factors is superior.

## F. THE JENSEN AND GATHMAN DATA

In two separate programs Gathman[3] collected and published data on the variability of measured aerosol extinctions in the visible.

In the figure below (Figure 4-8) it is clear there is a strong bimodal distribution in the character of the extinction at 0.55 μm with time. Clearly a prediction of transmission from the data in the first week shown would be a wildly optimistic prediction for the following week as evidenced by the second set of measured data in the following week.

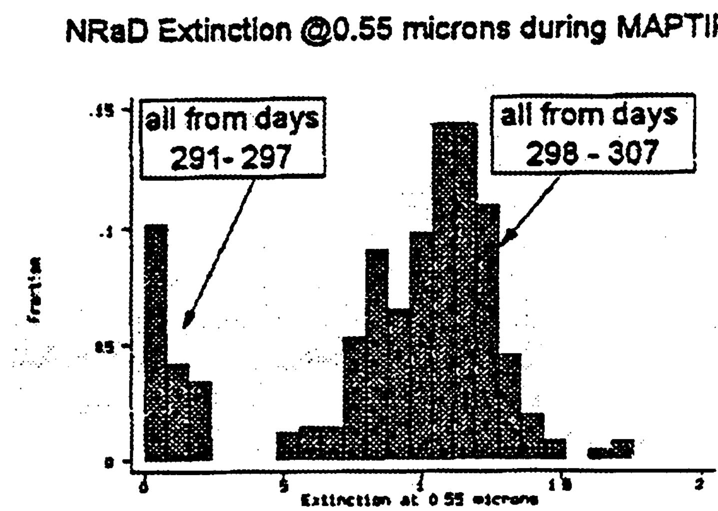


**Figure 4-8. Frequency of Extinctions**

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[3] Gathman, S.G. and D.R. Jensen, *Aerosol Maps Made During MAPTIP*, Ocean and Atmospheric Sciences Division, NCCOSC RDTE Div. 543, San Diego, CA.

Further, in the same vein the work of Jensen and Bull[4] on the transmission in the 3-5 μ and the 8-12 μ bands are shown for a month of measurements in May 1994 in a path of 7 km across San Diego Bay.

The following from Jensen and Bull shows the close correlation between transmission in Figures 4-9, 4-10, and 4-11; the relative humidity (primary) and the wind (secondary) are shown in Figure 4-12.

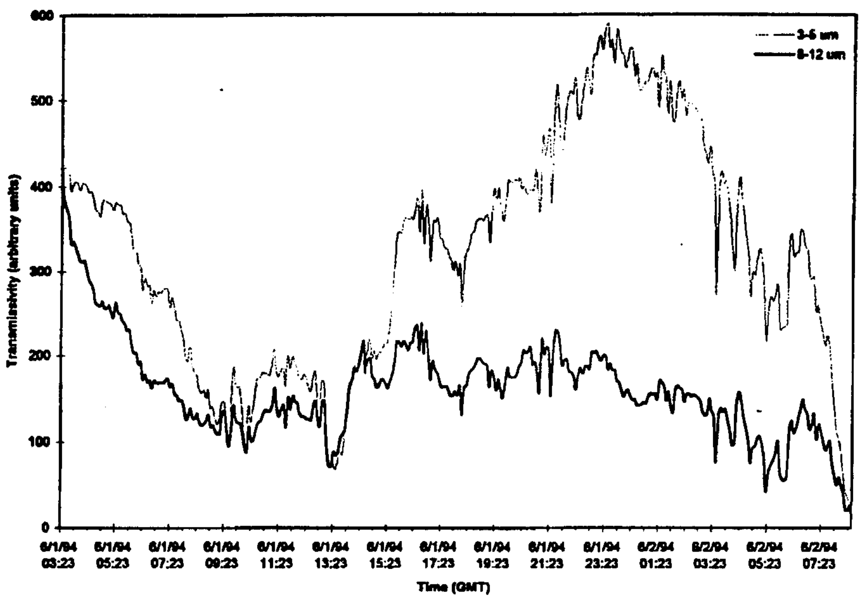


**Figure 4-9. Raw Comparative Transmissometer Data for June 1–2, 1994 (Figure 4 from Jensen, Bull)**

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4 Jensen, D.R. and H.T. Bull, Advisory Group for Aerospace Research and Development, Rept. AGARD-CP-567, Feb. 1995

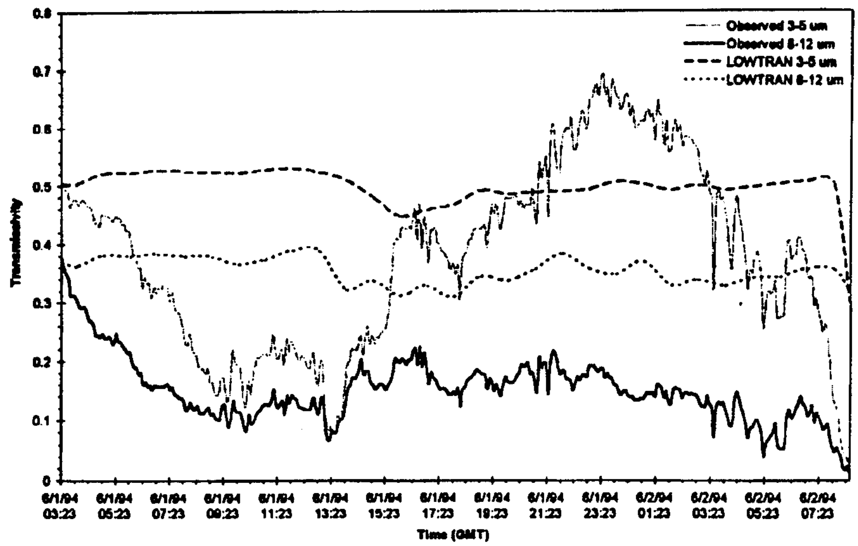


**Figure 4-10. Observed Changes in IR Transmission (Normalized to LOWTRAN) for June 1–2, 1994 (Figure 5 from Jensen, Bull)**

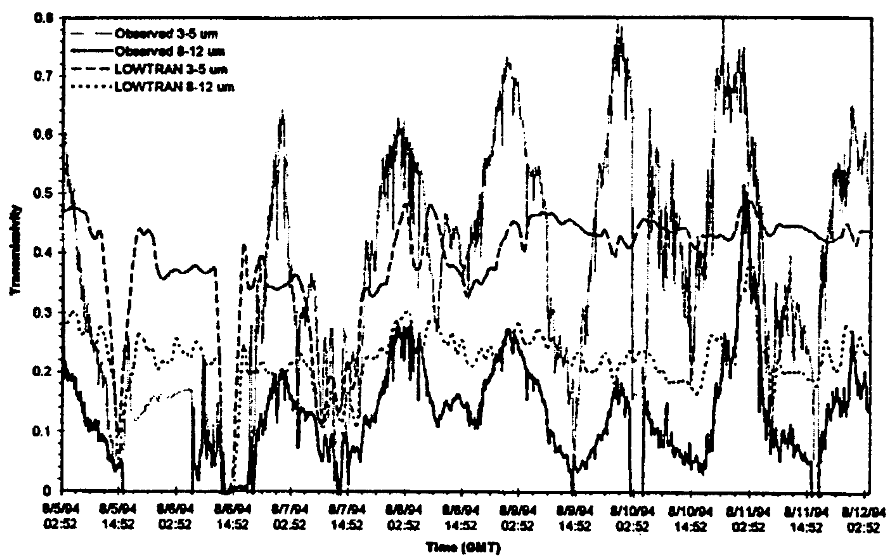


**Figure 4-11. Observed Changes in IR Transmission (Normalized to LOWTRAN) for August 5–12, 1994 (Figure 9 from Jensen, Bull)**

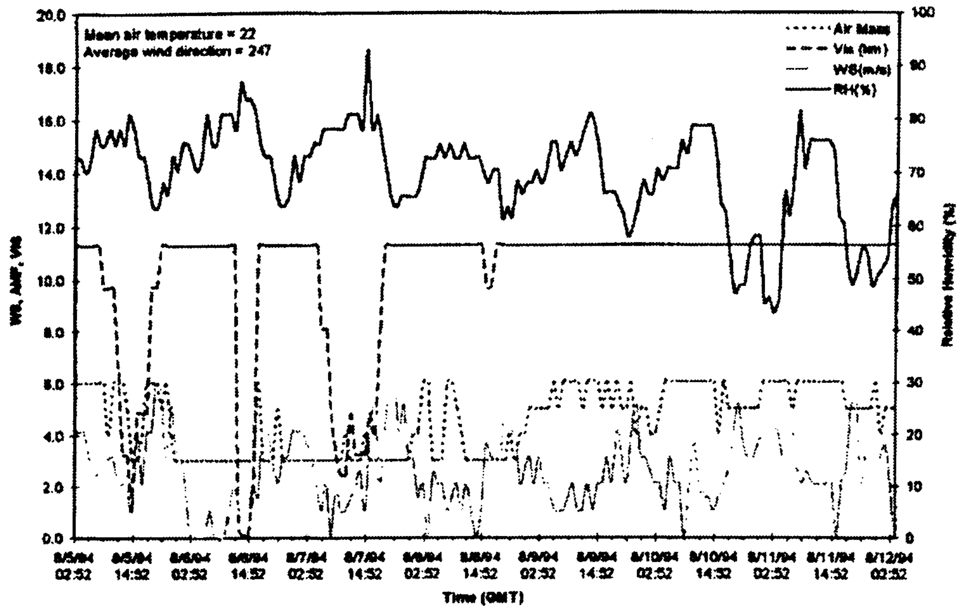


**Figure 4-12. Meteorological Data for August 5-12, 1994 (Figure 10 from Jensen, Bull)**

It should be obvious for this set of data that the variations seem to show a strong diurnal pattern with rapid major changes superimposed as new fronts move through, making the prediction for an estimate of future atmospheric transmissions difficult indeed.

Further, it is clear that a representation to a program manager attempting to equip his vehicle or platform with a new sensor must indicate the levels of probability with which such a device will acquire the target of interest under various target operating conditions and under the spread of transmissions at the season and location of interest, as well as variations in location, etc.

# V. SOME OBSERVATIONS CONCERNING SPECTRAL UTILITY

Clearly if one specifies an extinction and a sensitivity for a sensor, one can predict with reasonable assurance some range at which a device might be effective, all other factors being constant. However, there seems not to be a single typical extinction and the data show a spread of more than 10 in extinction for the cases we examined so far and this implies a factor of at least 3 in range.

In addition, the transmission comparisons shown in Section IV do not show the effects of different system sensitivities in the 3.8–4.2 μ, the 3.4–5.0 μ, and the 8–10 μ bands, nor do they show the effects of the different target signatures in the two bands.

If one convolves these three factors, one obtains the equivalent of the signal-to-noise ratio of the target excluding its background. In the following data we have ignored the factors representing the powers of 10 following the system sensitivity usually given as XXX E -NNN[5] and used only the XXX, as we are attempting to show the variability in the signal-to-noise ratio for cases of the spread due to variations in target and atmospheres that might be encountered by a single reasonably state-of-the-art IRST sensor.

Since for any one target and aspect, and any one sensor, the factor of merit can be seen to be a constant representing the target signal-to-noise ratio divided by the NEI of the system. This number multiplied by the atmospheric transmission, for some particular range, is related to signal-to-noise ratio, but does not include other range effects.

The data resulting from such calculations and the histograms based upon that data were obtained from the target signature data and the large-scale atmospheric data bases. Unfortunately, the exact choice of the bands was made by those who collected the data, and they *do not exactly match* the target signature bands. Further, the data on average plume emission cannot be multiplied by average atmospheric transmission with any reasonable expectation of an accurate answer representing the flux at the input window of the sensor.

5 That is, "NNN" has no real meaning.

Our primary purpose was to show that one single value of computed detection range (whatever that is supposed to mean without defining the probability of detection) has no real value for an operational user since the spread of the data is very large if one compares results at several locations, seasons, and times of day.

We must point out that *we have no relevant data on atmospheric transmission variability in the 3.4–5.0 micron region*, though we do have sensor NEI and target spectral radiant intensity data.

Thus, with some misgivings, but with a determination to get a reasonable if rough estimate of a similar quantity for a spectral band choice for an IRST, we adopted the procedure described below:

1. First, we computed the spectral radiant intensity of the target, using a band model, SIRIS, including blackbody, plume, earth shine, and solar contributions at 20 wavenumber resolution.
2. We then used the ONTAR PCModWin to compute the atmospheric transmission for a 5 km range also at 20 wavenumbers.
3. We multiplied these values by the reciprocal of the NEI of the sensor to produce a single value representing an average condition, though modeled, for San Nicolas Island.
4. We then convolved an interim product of the target divided by NEI in the 3.4–5.0 micron region and multiplied the interim product with each of the transmissions at 3.8–4.2 microns—*clearly a violation of good practice.*

We then plotted a histogram of those results, found a mean of the signal to noise in the histogram and replotted so that that mean occurred at the same value of S/N as the value based on the Modtran calculation discussed above.

The following assumptions govern this procedure:

- The shape of the aerosol spectral extinction curve does not change much in the interval from 3.4 to 5.0 microns, thus the use of 3.8–4.2 aerosol data for the region 3.4–5.0 does not introduce a significant error when compared to the variation of the aerosols with weather variations.
- Further, in the region 3.8–5.0 the variations due to atmospheric water vapor do not seriously affect the overall results since San Nicolas is temperate and the temperature changes affecting the extinction variations due to water vapor or its concentrations again are small compared to the aerosols.

With that sort of caveat, and a full realization that the data merely indicated what we need to better understand, we show the following histograms (Figure 5-1).

First, we show a comparison of the same data on a histogram with an abscissa of 0 to 120 and one plotted from 0 to 10. The 0 to 120 scale was chosen to show the relative performance that might be achieved in the three bands of major interest, remembering that the data in the 3–5 band will be somewhat to very optimistic.

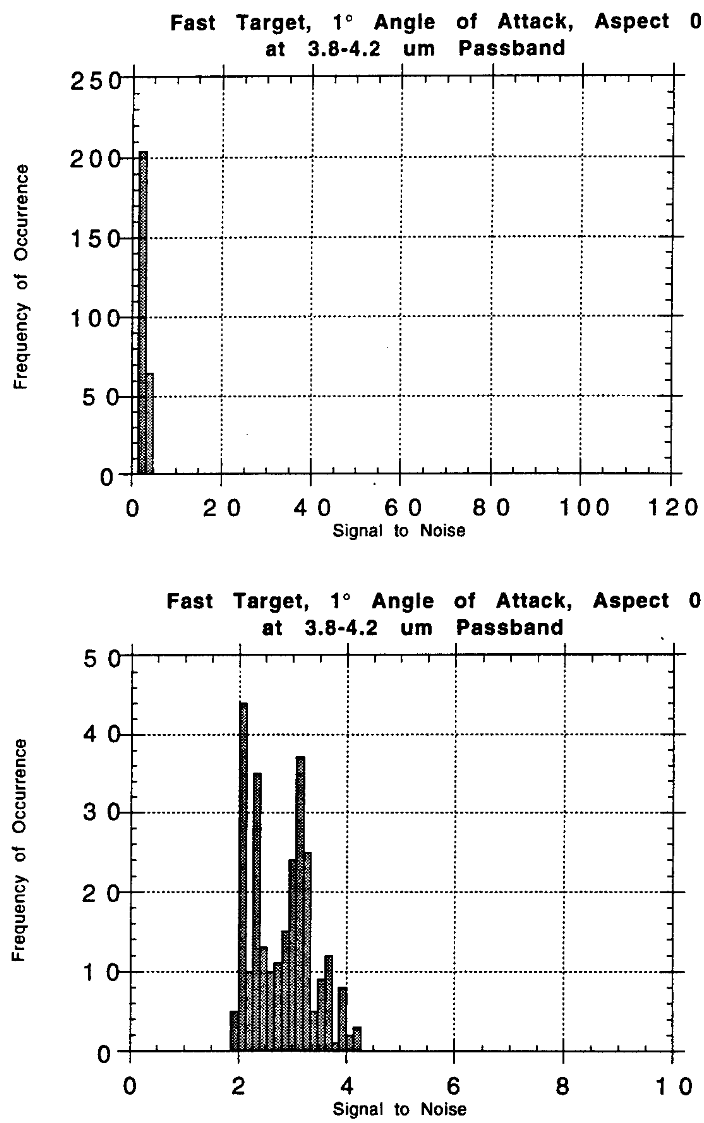


**Figure 5-1. Effect of Scale on Histogram Data**

We then show four target conditions (slow and fast, 0° and 8° aspect), as seen in three bands (Figures 5-2 and 5-3).

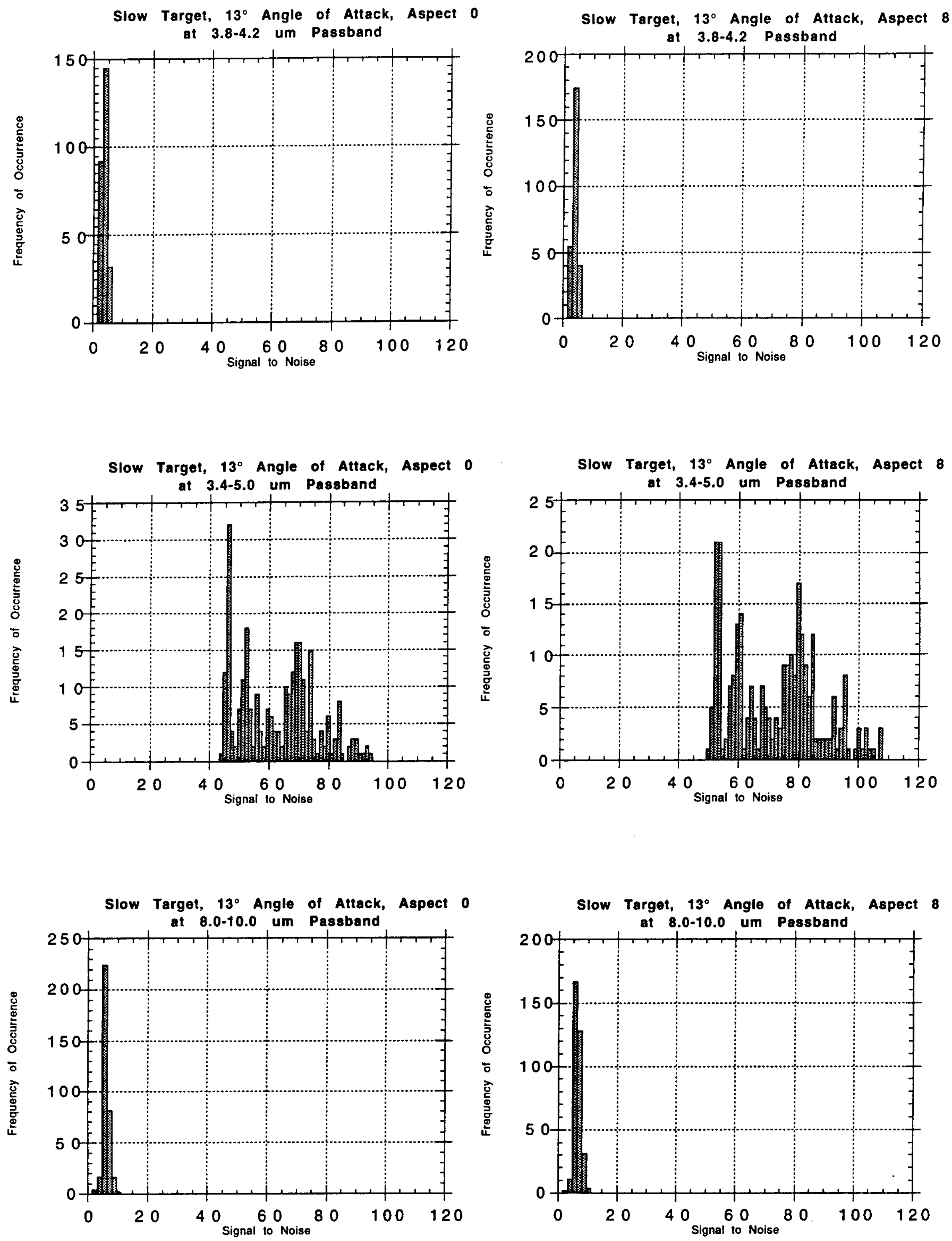


**Figure 5-2. Comparison of Signal-to-Noise Ratio for Slow Targets**

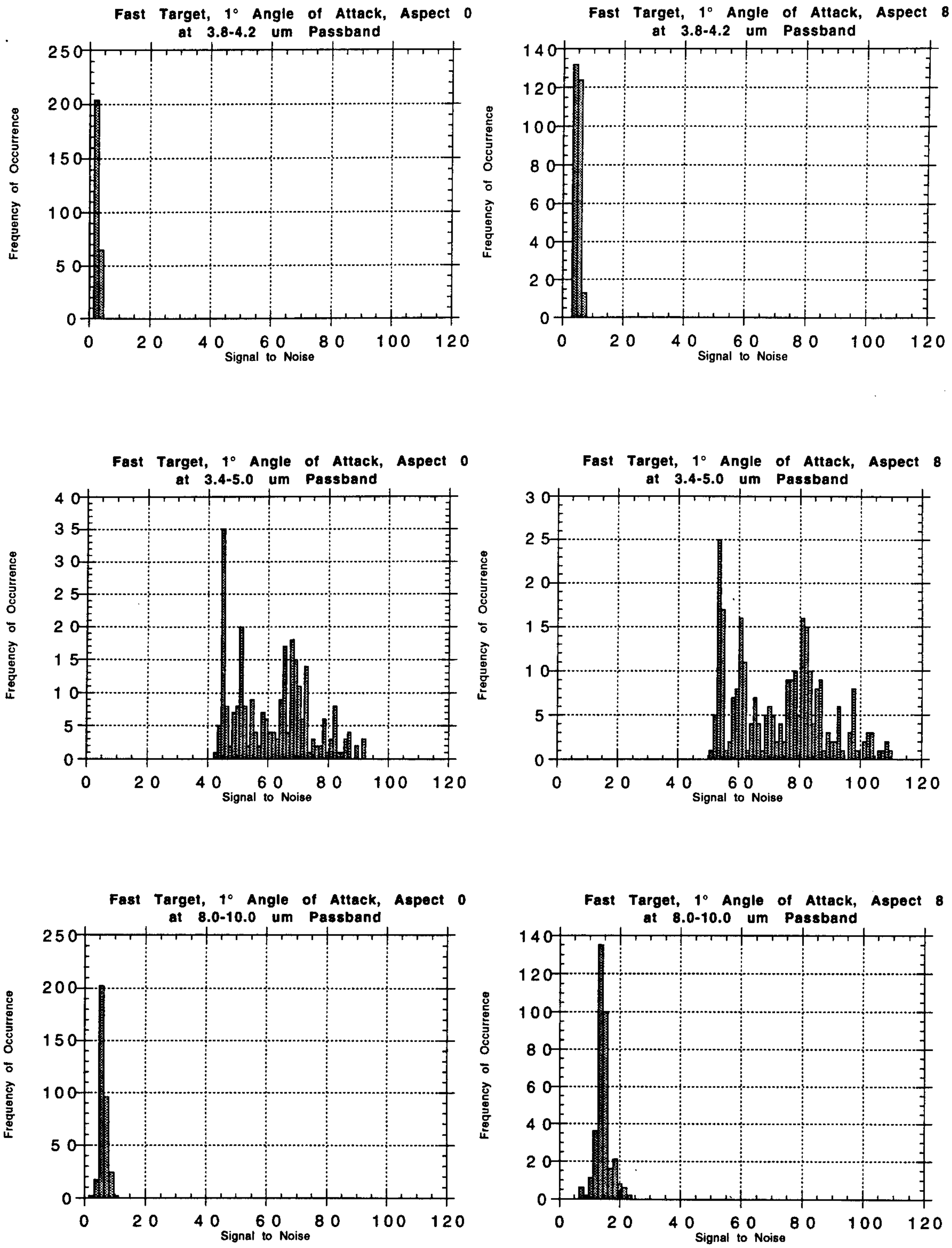


**Figure 5-3. Comparison of Signal-to-Noise Ratio for Fast Targets**

## A. AIRBORNE LOW-ALTITUDE APPROACHING TARGETS

When we began this study there was considerable interest in the 3.8–4.2 micron and the 8–10 micron bands. Clearly, these bands do not show much plume contribution due to hot gaseous emission but represent the grey body contributions of the target mach heating plus any contributions from solids in the plume. Thus we also examined the bandpass of 3.4–5.0 microns.

If we wish to use a proposed infrared equipment for a specific target and would like to compare passbands, we should examine the product of target spectral radiant intensity times the detector response times the atmospheric transmission at the range of interest. For any specific case the detector and target properties are fixed values but, as we have discussed previously, the atmosphere can vary dramatically.

To do the analysis properly one must be sure that the spectral band for the target, detector, and atmosphere are identical. For this study that was not feasible, thus, as a first approximation in the middle infrared we matched the 3.8–4.2 data with the OSP transmission in the 3.73–3.9 band as the closest and rather reasonable match and used the data for the target in the bands shown. This is not a rigorous means of analysis, but must be considered an indication of what needs to be done with better data than we presently have available on the statistical variation in atmospherics. We understand target signatures rather well, but the product of those signatures with less than appropriate atmospheric data indicates that great caution is needed.

Similarly the choice of the 8–10 band for calculations while the measured data are in the 8.33–11.9 band results in the best match we could make, and again this is very small compared to variation with aspect and variations in transmission over time and place.

We showed in Figures 5-2 and 5-3 a set of histograms that, for San Nicolas Island, clearly show the probable superiority of a passband at 3.4–5 microns over the bands at 3.8–4.2 and 8–10 microns, even after noting the caveats in the above paragraphs.

When we began this study there was considerable interest in the 3.8–4.2 micron and the 8–10 micron bands. Clearly, while these bands represent the gray body contributions of the target aerodynamic heating plus any contribution from solids in the plume, they do not show much of a contribution from the plume hot gas emission. Thus, we also examined the bandpass of 3.4–5.0 microns.

Table 5-1 shows an approximate summary of the histogram data. It shows the values and spread in the factors of performance merit for the two targets at their normal

angles of attack, seen nose on and from an aspect angle of 8 degrees off nose. Clearly, for the San Nicolas environment the choice of the 3.4–5.0 micron band appears, in spite of the caveats mentioned above, the best choice most of the time. From the frequency-of-occurrence versus factor-of-performance merit histograms, there are no outliers in the 3.8–4.2 or the 8–10 bands to justify their choice of an alternate at San Nicolas. The notation "slow, 13/8" means a slow target flying with an angle of attack of 13° seen from 8° off the nose.

**Table 5-1. Factors of Performance Merit Against Low Airborne Targets**

| Band/target | Slow, 13/0 | Slow, 13/8 | Fast, 1/0 | Fast, 1/8 |
|---|---|---|---|---|
| 3.8–4.2 | 100–250 | 100–250 | 75–175 | 200–400 |
| 3.4–5.0 | 1,500–3,000 | 1,500–3,000 | 700–1,500 | 2,000–4,000 |
| 8.0–10.0 | 300–600 | 300–600 | 100–700 | 900–1,500 |

Even though we have shown above that there are a significant number of times when the 8–10 passband transmission exceeds the shorter wavelength transmission, by the time the character of the targets chosen and the detector performance in the chosen bands are considered, the outliers at 8–10 are dwarfed by the effect of the spectral radiant intensity of the targets—again for the conditions at San Nicolas Island.

If one wishes to use a more conventional set of calculations, one might well choose the SPIRITS and the MODTRAN models. With these models one calculates in some detail the target radiant intensity in a given band and subtracts the background (including path radiance) to obtain what is often called thermal contrast.

We performed such calculations on the two targets used in the figures presented earlier, but at a longer range, 27 km, each in the 3.4–5.0 and the 8.0–10.0 band, and each at their normal angles of attack seen nose on and 8° off the nose. Table 5-2 shows these results.

The results are somewhat similar to the previous set of factor of performance merit calculations but differ by about a factor of 100 due to the scaling factors.

In Table 5-1 the 3.4–5.0 band is about 2–5 or so times as great as the results for the 8–10 band. In Table 5-2 the contrast computed for the same cases is about 5–6 times as great as in the 8–10 band.

Note that in the 8–10 region the target signal and background appear identical. They are unless one looks beyond the third significant figure—the author for one does not trust any model that far! The reduced S/N is due largely to the lessened target signal while the background plus path radiance is larger. It is not clear there is a more appropriate means of comparing effectiveness without bringing in the clutter and algorithms to process clutter.

**Table 5-2. Contrast of Slow and Fast Targets**

| Target | Band | Signal | Background | Contrast |
|---|---|---|---|---|
| Slow, 13/0 | 3.4–5.0 | 88 | 72 | 16 |
| | 8.0–10.0 | 857 | 856 | 1 |
| Slow, 13/8 | 3.4–5.0 | 89 | 72 | 17 |
| | 8.0–10.0 | 857 | 856 | <1 |
| Fast, 1/0 | 3.4–5.0 | 78 | 72 | 6 |
| | 8.0–10.0 | 857 | 856 | 1 |
| Fast, 1/8 | 3.4–5.0 | 85 | 72 | 13 |
| | 8.0–10.0 | 857 | 856 | 1 |

Thus, for the IRST applications against low altitude targets the 3.4–5.0 band appears to be the band of choice.

## B. OPERATIONAL OPERATING TANK TARGET SIDE ASPECT, DOMINATED PRIMARILY BY TREAD REGION

Using the model developed by Roberts, Deller, and Biberman, calculations were carried out assuming the bogey wheels and tracked area showed a thermal contrast with the terrain background. We can show the range prediction for target recognition for a modern FLIR at probabilities of about 50, 80, and 95 percent (Figure 5-4).

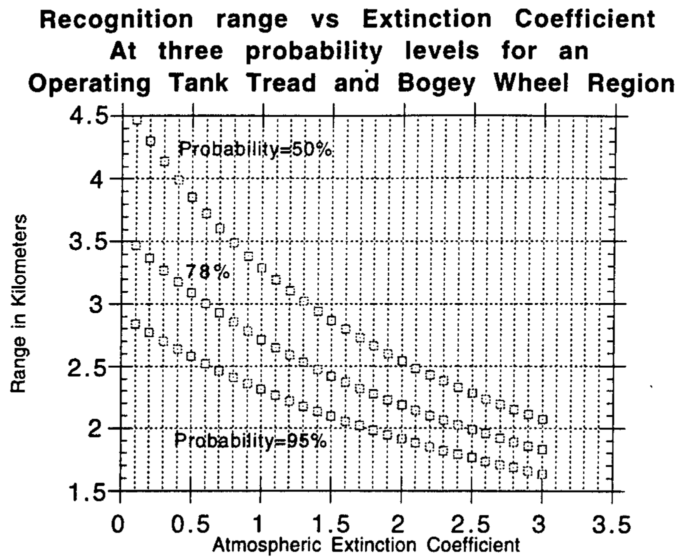


**Figure 5-4. Range vs. Extinction for One Typical Target**

If one now looks at the extinction coefficients in the data prepared by Hepfer for all latitudes, as shown in Figure 5-5, one can see that the frequency of occurrence of weather adequate to recognize targets depends both on the extinction necessarily being below some value shown above as well as the frequency of occurrence of extinctions at those levels.

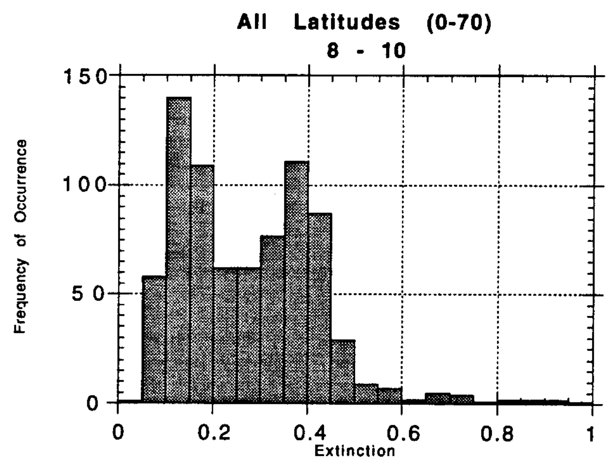


**Figure 5-5. Typical Variation in Extinction**

Thus, according to the data collected and computed by Hepfer one can estimate the recognition of the treads and bogey wheel section of an operating (hot) tank at 4 km at a 50 percent probability, out to about 3.3 km at about an 80 percent probability, and a little over 2.5 km at 95 percent probability.

The numbers are about right in a comparative sense but are dependent upon the particular sensor used; more importantly, they depend upon the degree of clutter in the background and of course the target status and its aspect as seen by the sensor.

It must be noted that recent mid-latitude, easy coast air-to-ground flight trials using a staring 3–5 FLIR has shown some very fine results. The use of the staring sensor with the narrower bandwidths necessary to prevent saturation and the higher energy of each photon in that region, makes this region of sufficient interest.

Since the fleet must be ready to leave one region and report to another ready to operate under the needs and prevailing conditions there, we looked at the Hepfer data and then at Figure 5-5. The Hepfer data indicated few cases where the extinction would exceed 0.4/km, thus the total times that the mid-IR would be penalized relative to the longer wave region seems to be one more serious reason to favor the mid-IR band for ground to air. However, one must remember that data within that region is still quite scarce and the statistics almost non-existent. If, however, air-to-ground operations are a prime consideration, the vagaries of the atmosphere make a dual band solution very important. By dual bands we specifically mean two separate and independent bands in the 3–5 and the 8–10 region. We do not mean both bands operating simultaneously with appropriate algorithms to optimize the combined use of data from each.

# VI. THE CASE FOR DUAL BANDS

If one were to rely on the data collected by OSP and that processed by Hepfer, it would seem there is no need to use any band except the band in the 3.4–5 micron region for IRST applications against low-altitude targets.

However, that data is old and we have real questions about how the weather was sampled during the collection process.

In addition, there are conflicts between the collected extinction data and recent imagery as noted below:

1. The data collected by the OSP program, as processed by Battalino, shows that the Navy aerosol model matched the measured data reasonably well, and Hepfer used the Navy aerosol model.
2. Recorded FLIR imagery, as collected by Steve Campana in recent months, shows beautiful terrain imagery taken from the air in the 3–5 micron region.
3. Recorded imagery taken at surface level of shipping shows that 8–10 is superior in the low absolute humidity, higher relative humidity environment of Maine coastal waters, while the 3–5 micron band is far superior in the high absolute low relative humidity in the littoral waters of the Gulf of Mexico.

Clearly, better data and more complete information and understanding of the problem are needed before one can confidently choose one over another.

It concerns the author that the existing old data may be based upon data taken when the weather was good enough to measure transmission over reasonable ranges, and that no effort may have been made to collect data when the weather fell below such conditions.

Since we know little about the sampling process, we find it hard to base a recommendation for either band on the 1970's data. Recent imagery also strongly contradicts our findings based upon the old data, at least for surface targets such as ships and terrain features. From the imagery alone it would appear that a change of duty station (e.g., from the low absolute humidity with moderate relative humidity in the littoral waters off Maine to the high absolute humidity but clear weather of the Gulf off the Texas coast) would indicate a change in the sensor band or a dual band sensor.

Since the fleet must be ready to travel from almost any latitude to any other and be ready for immediate operations, we believe the dual bands are necessary especially for air-to-surface applications. We repeat that by dual bands we specifically mean two separate and independent bands in the 3–5 and the 8–10 regions. The exact bands must be more carefully determined than we have in this paper. At present, we specifically do not mean both bands would operate simultaneously with appropriate algorithms to optimize the combined use of data from each.

## VII. CONCLUSIONS

Probably our most important conclusion may be stated as follows:

> Since the performance of most infrared systems varies with the atmospheric transmission of the path, all else being equal, it can be seen that weather is a major driver in the performance of such systems. The IR sensor performance is tightly related to the local conditions, and thus the season and location of operation, etc.

Further, we have shown there is no single meaningful value for system performance; rather, performance is best described by a broad roughly bell-shaped curve for any one location and season.

From the data presented above, one can draw the following additional conclusions:

1. From all of the plots in the previous sections of this paper, one can judge the percentage of time an infrared system faces a given transmission. If one then specifies the target radiant intensity in a chosen band, the sensor in that band, and the absence of clutter, one can predict a range for a given probability. However, the range performance will be largely determined by the temporal variation, weather, and background structure, although there is little such data upon which to predict that performance.

2. The atmosphere can have fairly high absolute humidity yet low relative humidity and vice versa. When the relative humidity is high but absolute humidity is low, as in colder regions of the earth, aerosols tend to form and are a problem; fog may or may not result and the shorter wavelengths suffer. Thus, in these conditions, the longer wavelength band tends to be superior. On the other hand, places like the Gulf of Mexico off the Texas coast can have fairly high absolute humidity but low relative humidity with few aerosols and high total transmission in the 3–5 micron wavelength band.

3. In our examination of the places for which we had data, the 3.8–4.2 band exhibited higher transmissions more of the time than did the 8–10 band. The 8–10 band is better when aerosol conditions are severe for long range transmissions, but these transmissions may be at levels where the transmission may be too low to be useful for some applications and sensors.

4. From an examination of the previously shown data, we believe the use of a dual band instrument is a choice that can be justified on the basis of atmospheric transmission if both low altitude airborne as well as surface

targets are of interest. If only the threat of airborne low altitude attacks is considered, then the choice of the 3–5 micron band alone is warranted.

5. In the case of the Navy, a maritime environment and a very wide array of targets from the very hot to near ambient—a real problem exists in choice of band, and it well may be that dual band operation is the most practical solution for Navy vessels that travel around the world.

6. In the case of the Army, prior experience with the various antecedents of the common module FLIR showed that longer wavelengths were more effective than the 3–5 band FLIRs of that period. Thus, the 8–10 band was adopted for the recent generation of focal plane array FLIRs. What is not established is the range at which such FLIRs will perform against a variety of ground based targets, near ambient, in a wide variety of geographic locations, seasons, and atmospheres. Some advocate a return to the 3–5 band. The imagery we have seen from Maine and Texas seems to show a real need for dual bands. The value of dual band equipment seems to be tentatively answered if worldwide application at high performance is to be achieved.

7. One might look at the problem as if the probability of sensor performance versus range is something like a bimodal pair of bell shaped curves, the center point of which is located for any one target at some range determined by sensor parameters while the spread in the bell curve is related to the variations introduced by all the environmental parameters. In the case of San Nicolas Island alone, this yields a spread of three to one.

The conclusions reached so far apply only to the data examined. Those data are primarily representative of conditions at sea and in the littoral regions of interest to the Navy.

We have been unable to obtain the *data* over land that was extensively recorded over several years at various littoral and land mass locations in the European continent. Reports exist for those data-gathering activities, but the actual data appears to have disappeared from the face of the earth.

One additional remark seems necessary at this point. The staring focal plane array appears to offer significantly improved performance to imaging sensors such as FLIRs, especially in the 3–5 micron region, given careful design choices. The problem is there are so many energetic photons in that region that a narrowing of the band is necessary to prevent overfilling the storage wells. That would appear to permit choosing an optimum narrower band. In the 1970's, technology was not available to determine such an optimum narrower band.

This paper did not consider the problem of lack of suitable narrow band data, though inferences could be made although not verified. Work to collect and analyze that kind of narrow data is needed to optimize the choice of spectral band before final designs for FLIRs in that band are accepted for production.

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# APPENDIX A

# THE NRL MEASUREMENTS AT SAN NICOLAS ISLAND

# APPENDIX A
# THE NRL MEASUREMENTS AT SAN NICOLAS ISLAND

It is easy to show, using *averaged* data, what the transmission or extinction coefficients are apt to be in subartic winter and mid-latitude summer for comparison with the San Nicolas Island data, but such averaged data is a poor criteria on which to design equipment. Fortunately, the data rescued from NRL and OSP has given us some limited marine data.

The data in Figure A-1 was taken from NRL Report 8618,[1] being the best source of statistics for temporal variation in extinction available to us at the time of preparing or printing this report. We note but are unable to explain that the extinctions for 0.55 and 1.06 microns are closely bunched or even reversed in level from that which we would have expected from Mie theory. On the following two pages Figure A-1 shows the variation in the aerosol extinction coefficient, in four bands, as a function of time of day.

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1 NRL Report 8618, *Results of Laser-Calibrated High-Resolution Transmission Measurements and Comparisons with Broad Band Transmission Data: San Nicholas Island, California, May 1979*, published September 30, 1982.

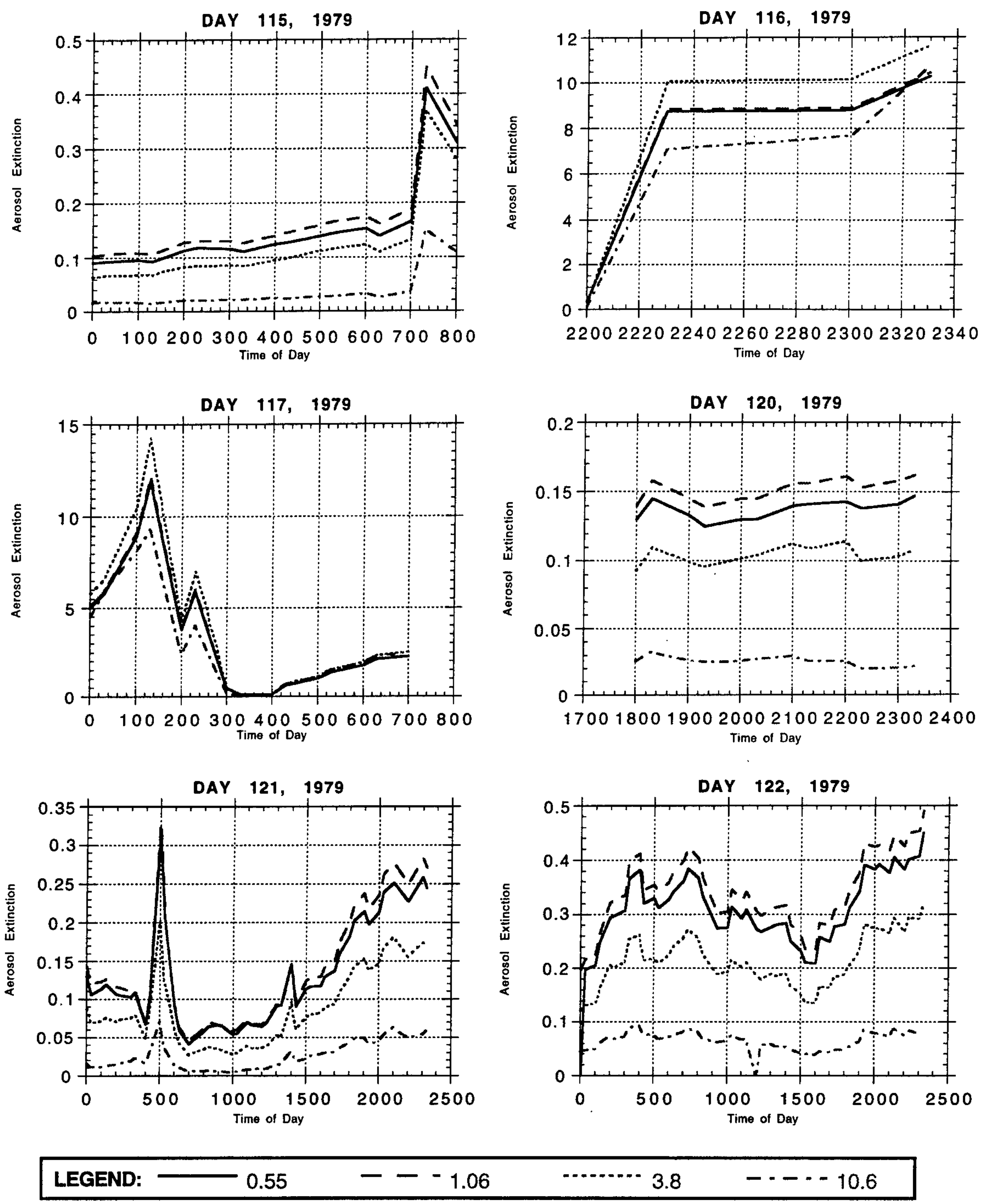



**Figure A-1. NRL Data, San Nicolas Island**
**Days 115 through 122, 1979—Aerosol Extinction Coefficient in 4 Bands.**
**Note the drastic changes in scale for the extinctions from day to day.**

I do not have an explanation for the relative position of the aerosol extinctions at 0.55 and 1.06 Microns.

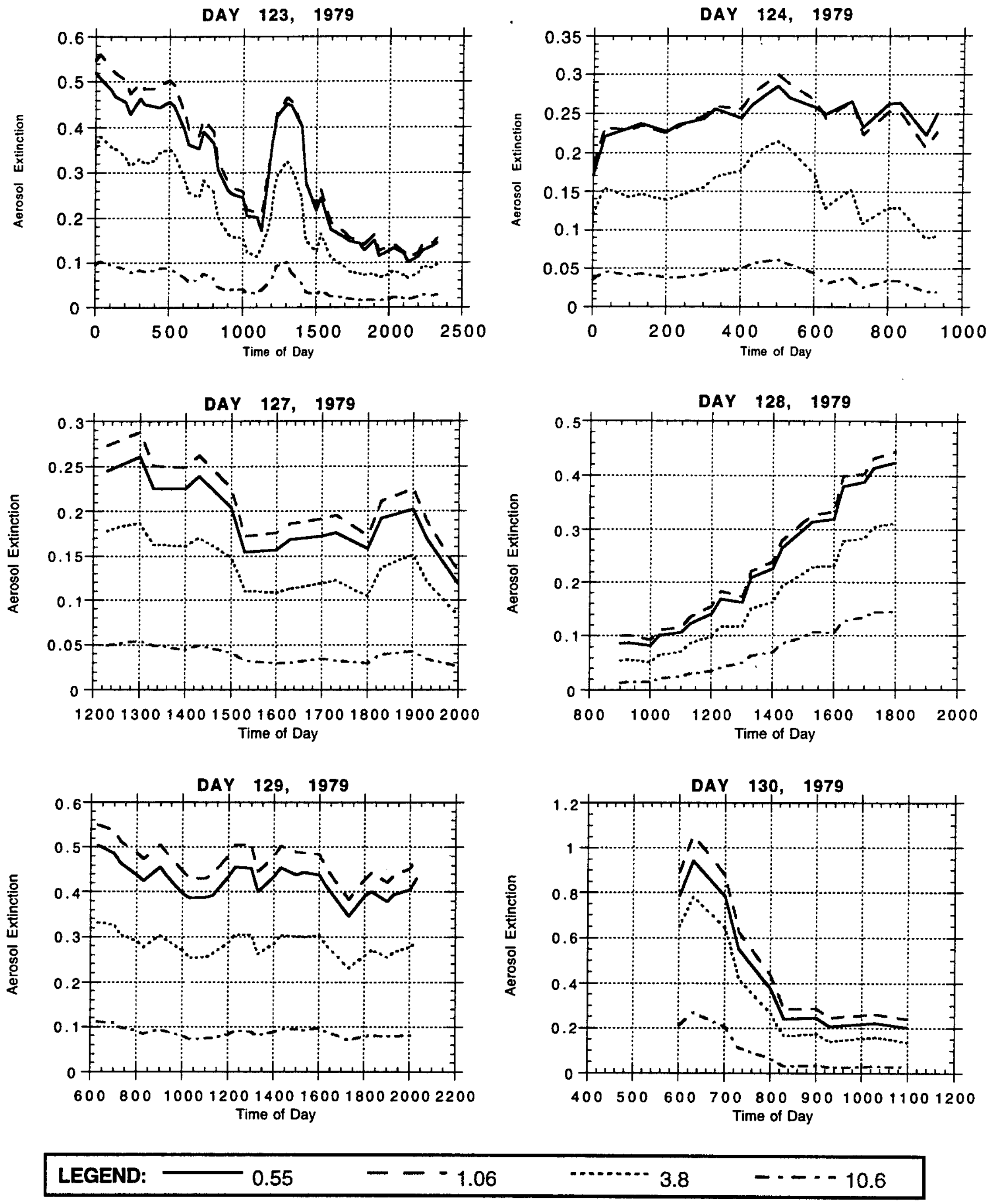
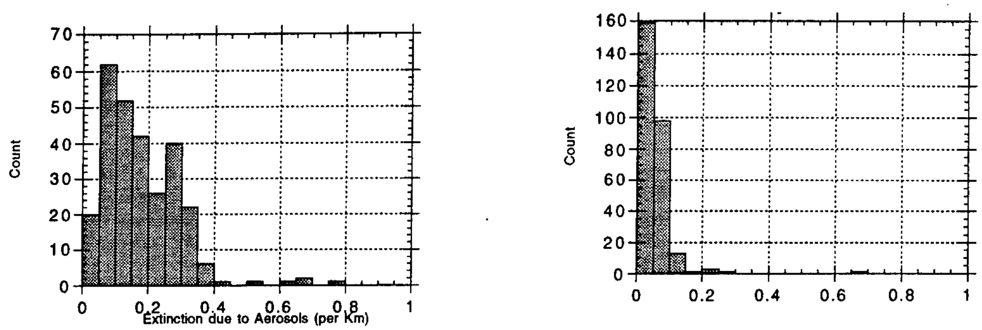



**Figure A-1 (Continued). NRL Data, San Nicolas Island Days 123 through 130, 1979—Aerosol Extinction Coefficient in 4 Bands. Note the drastic changes in scale for the extinctions from day to day.**

The following two histograms (Figure A-2) show the distribution of extinction coefficients for the aerosols measured at San Nicolas Island during May 1979 (the left figure is at 3.8-4.1 and the right figure is at 10.6). The extinctions plotted are for values of extinction per km, but measured over a 4.07 km path at 3.8 and 10.6 microns. Further, there are some misgivings about the data from San Nicolas Island due to the proximity of breaking surf near and under the path from source to receiver. The low values indicate a relatively clear day and little effect from the surf. The higher values could be from heavy haze drifting in from the sea or from heavier surf—it is difficult without the raw annotated data to tell which. The same remarks could be repeated after the collection of plotted data shown in Figure A-1.




Extinction Coefficient at 3.8 microns          Extinction Coefficient at 10.6 microns

**Figure A-2. Distribution of Extinction Coefficients for the Aerosols Measured at San Nicolas Island, May 1979**

Here the atmospheric extinction *without aerosols* would be expected to heavily favor the utility of the 3.8-4.2 band over the 8-10 because of the relatively small extinction at 3.8 due to water and water continuum at the shorter wavelengths, while the water vapor continuum is rather severe at 10 in the high humidity of summer. This one set of data is quite different from most of the other data examined in that the 10.6 appears better than the 3.8-4.2 data.

# APPENDIX B

# THE SAN NICOLAS ISLAND ELECTRO-OPTICAL METEOROLOGY AND OPTICAL SIGNATURES PROGRAM (SNI EOMET/OSP) DATA

# APPENDIX B
# THE SAN NICOLAS ISLAND ELECTRO-OPTICAL METEOROLOGY AND OPTICAL SIGNATURES PROGRAM (SNI EOMET/OSP) DATA

As indicated previously, Terry Battalino of Pt. Mugu has processed several high activity periods of the OSP program at San Nicolas Island.

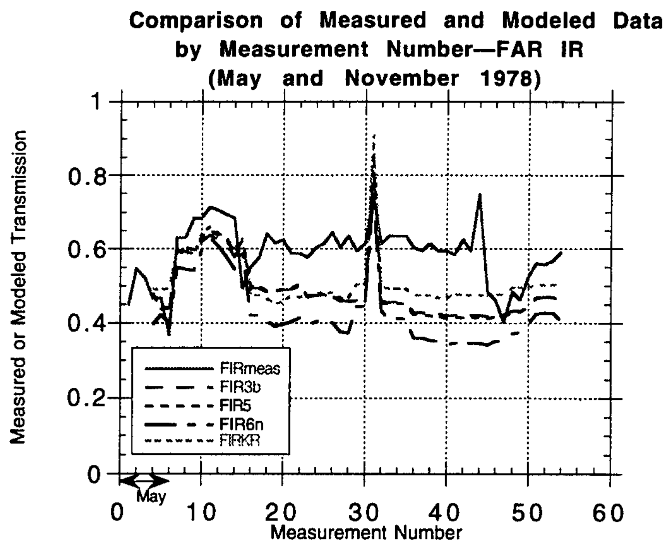



**Figure B-1. The Battalino Data for San Nicolas Island**

In Figure B-1 the solid line represents the measured data for the 8.33–11.9 micrometer band over a 4.067 km path while the four remaining curves represent modeling results for that band using the Katz-Rhunke model (labeled FIRKR in the legend), the next curve below KR is the LOWTRAN 3b calculation (FIR3b), the next is the LOWTRAN 5 (FIR5) as prepared by the USAF Geophysics Laboratory (Hanscomb Field, MA), the lowest curve is LOWTRAN 6 (FIR6n) using the Navy aerosol model.

It seems clear that the very general form of the measured and modeled data match fairly well, but that the measured data are clearly much higher in absolute values of transmission than that predicted by all four models. As yet we are unable to explain whether the radiometers were improperly calibrated, whether the models for the aerosol components are incorrect, or whether, as G. deLeeuw points out in private correspondence:

This may be occuring in very clean air where the sub-micron fraction has less mass, i.e., the mass distribution peaks around 1 um. In general I observe that the extinction from the UV to the NIR is fairly waelength independent over sea, in clean maritime air.

The Battalino OSP data for the 3.73 to 3.9 micron band shows considerably better match to the various models he used for comparison against measured data. Figures B-2 and B-3 below show all data for mid-IR in 1978 and 1979.

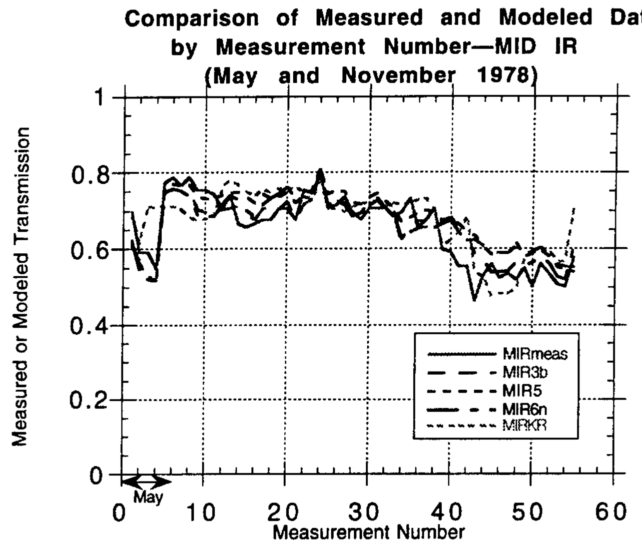



**Figure B-2. Comparison of Data (May and November 1978)**

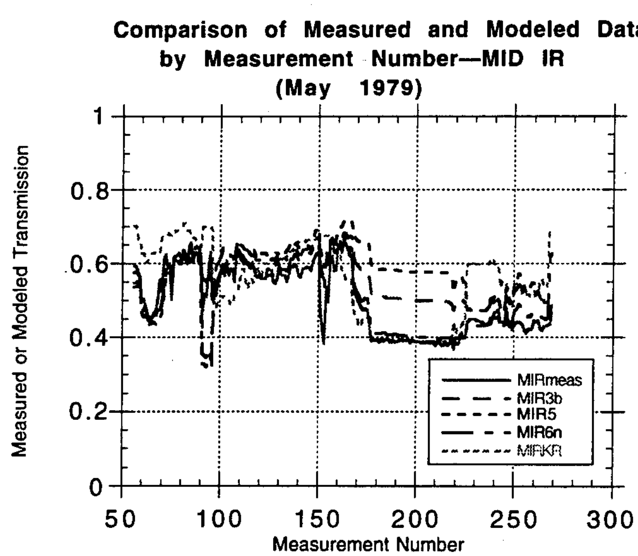



**Figure B-3. Comparison of Data (May 1979)**

Figure B-2 shows the best fit of the modeled 1970's data examined when the model used was the LOWTRAN 6 with the Navy maritime model. The other models show results that are up to 50 percent greater than the measured data. The 1978 modeled data fit much more closely to the measured data, but no single model is as good as the best in the 1979 data (Figure B-3).

It must be noted that Battalino has processed about half the available data, and further results from him—as he has the raw data—are needed before a complete review can be presented. Figure B-4 shows a summary of Battalino's records to date.

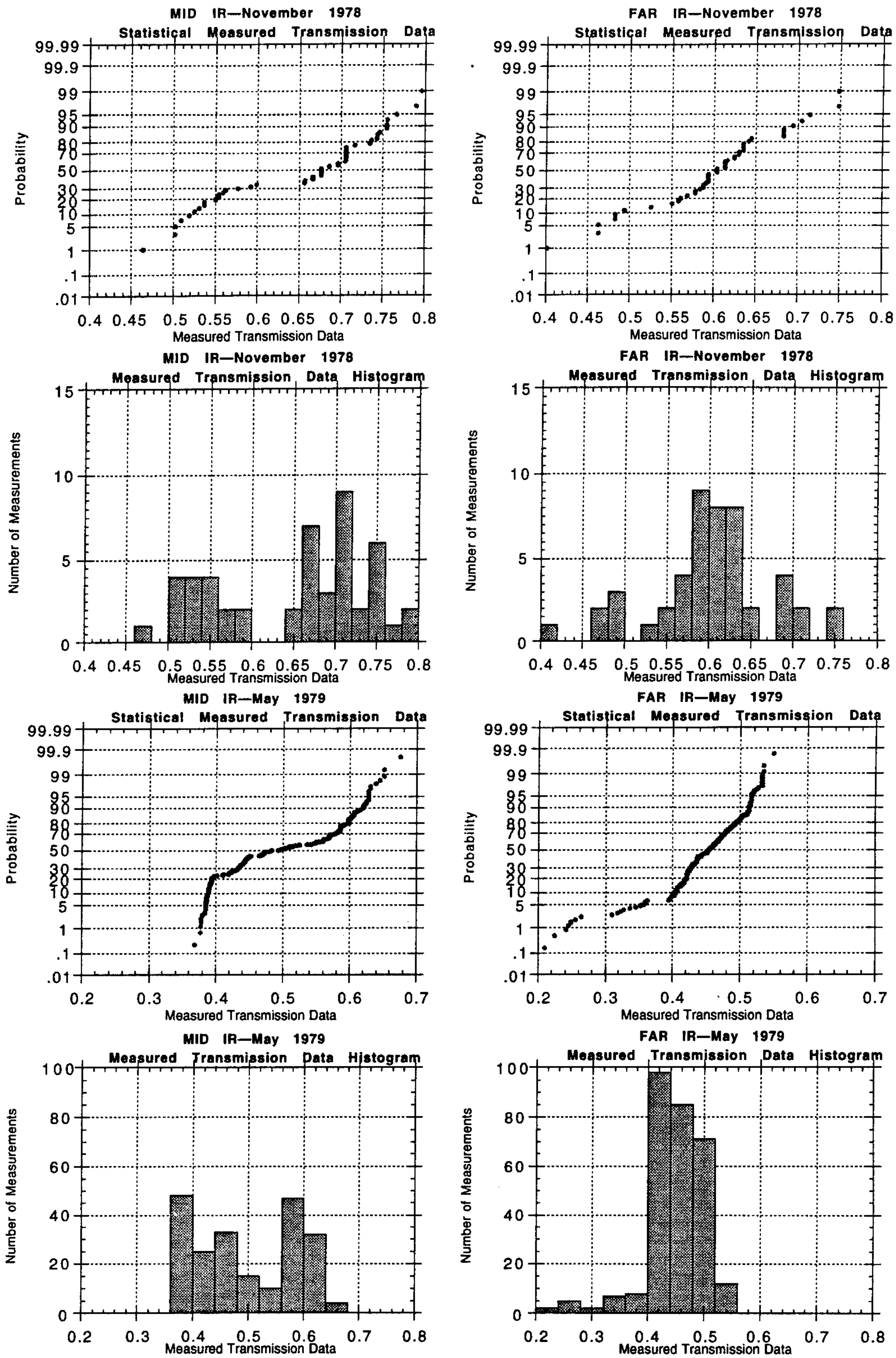



**Figure B-4. A Quick Summary of Battalino's Records**

# APPENDIX C

# THE NRL CAPE CANAVERAL DATA

# APPENDIX C
# THE NRL CAPE CANAVERAL DATA

Detailed description of the work and results of the NRL Data Compendium for Atmospheric Laser Propagation studies conducted at Cape Canaveral, Florida, February through May 1977, is given in NRL Report 3611, dated September 1977.

We include an excerpt from that NRL report:

## High-Resolution FTS Measurements

High-resolution atmospheric transmission measurements were made with an IDAC Model 1000 Fourier transform interferometer-spectrometer (FTS) system. A description of the FTS system and of its installation in the IMORL receiver trailer appears in NRL Report 8059 of September 1977.

For the 1977 Cape Canaveral experiments the interferometer was operated in two distinct modes, depending upon the spectral region being investigated.

For work in the 3 μm to 5 μm atmospheric window, the interferometer was configured with a $CaF_2$ beamsplitter and an InSb detector. Inteferograms of a graybody source in the IMORL transmitter trailer (5 km distant) were sampled at 128 K equally spaced points over a total optical retardation of 8 cm. To reduce noise levels in the resulting computed spectra, 100 interferometer scans were typically co-added prior to calculating the Fourier transform. The sampling process generally required about fifteen minutes.

For work in the 10 μm region, the FTS system was used with a KBr beamsplitter and a HgCdTe detector. The 8 cm optical retardation was retained, but the sampling was reduced to 64 K (equally spaced) points. Because the background radiation in this region is proportionately larger, separate "no-source" scans were also recorded. These reference interferograms provide data on the spectral distribution of the atmospheric background radiation, which must be separated from the graybody spectra before attempting an absolute transmission normalization. (To date, initial efforts to effect this separation by simply differencing the two types of interferogram prior to computing the Fourier transform have not proved satisfactory.)

Histograms of that data are shown below (Figure C-1).

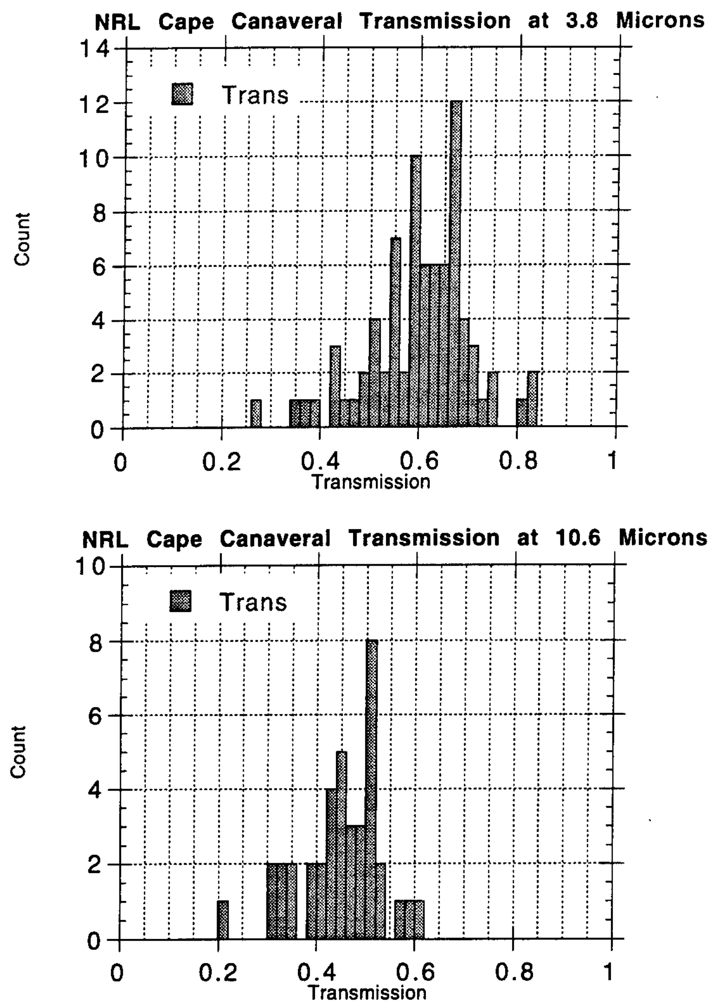



**Figure C-1. Variation of Transmission**

The transmission at 3.8 appears better than that at 10.6. However, this data must be taken with several grains of salt. Clearly, the techniques and talents employed in acquiring this data are beyond reproach, but these data represent laser emissions and transmissions, and extrapolation to broad band use (as might be employed in a FLIR or IRST) would be a dangerous extrapolation. Clearly these data represent the extinction in a very narrow spectral line and extrapolation across many lines in the broader optical windows leads to the type error that is best expressed by saying the average of exponentials is not the same as the exponential of averages. Here we would be assuming that the exponentials related to one of the 10.6 lines is an average of all the exponentials in a broader band around 10.6. Essentially we say that the Beer's Law approximation does not apply to any but monochromatic radiation.

Nevertheless, the distribution of transmissions indicated by the histograms is an indication of the spread in performance that is roughly related to the spread that might be expected in the 8-10 region.

# APPENDIX D

# THE HEPFER METEOROLOGICAL DATA COLLECTIONS

## APPENDIX D
## THE HEPFER METEOROLOGICAL DATA COLLECTIONS

Ken Hepfer of Naval Surface Weapons Center (NSWC) at Dahlgren, has compiled two collections of meteorological data known as R384 and R400.[1] These were compiled from observations made from ships at sea and other weather sources primarily at or near the sea. This data of wind speed and direction, temperatures, etc., were put through LOWTRAN using the Navy aerosol model to compute results shown below.

The following material is extracted from personal correspondence from Hepfer:

### R384 Environmental Sample

On 6/9/93 I put together another "World-Wide" environmental sample for use with the EO COEA. The sample is intended to represent 4 geographic areas with equal weight. The areas are:

Baltic Sea
Yellow Sea (Korea)
Gulf of Oman (Persian Gulf)
Caribbean Sea

It was desired to represent each area by 8 randomly selected weather samples per month for a total of 8 • 12 • 4 = 384 samples.

For the Caribbean Sea and the Gulf of Oman, I was able to do an exact selection of 8 samples per month using data from the NSWC WX database of 60 observations per month from 14 locations. For the Baltic Sea and the Yellow Sea, I made the samples up from available weather samples from the nearest areas. For the Baltic Sea, I had 72 observations from the Gulf of Finland which is just off the Baltic Sea. I supplemented these observations with 24 observations from Weather Ship J which is at approximately the same Latitude but in the open Ocean. The distribution of these samples was as follows:

1 Available only directly from Ken Hepfer of NSWC, Dahlgren.

| Month | Number of Observations | |
|---|---|---|
| | Gulf of Finland | Weather Ship J |
| Jan | 0 | 6 |
| Feb | 0 | 6 |
| Mar | 1 | 5 |
| Apr | 2 | 3 |
| May | 1 | 4 |
| Jun | 8 | 0 |
| Jul | 26 | 0 |
| Aug | 5 | 0 |
| Sep | 10 | 0 |
| Oct | 11 | 0 |
| Nov | 0 | 0 |
| Dec | 9 | 0 |

For the Yellow Sea, I had 77 observations from the region between the Yellow Sea and the East China Sea. I will refer to these 77 samples as "Yellow Sea." I supplemented these observations with 19 observations from the central portion of the East China Sea. The distribution of these samples was as follows:

| Month | Number of Observations | |
|---|---|---|
| | Gulf of Finland | Weather Ship J |
| Jan | 8 | 0 |
| Feb | 1 | 7 |
| Mar | 7 | 1 |
| Apr | 4 | 4 |
| May | 3 | 5 |
| Jun | 7 | 1 |
| Jul | 9 | 0 |
| Aug | 7 | 0 |
| Sep | 8 | 0 |
| Oct | 10 | 0 |
| Nov | 4 | 1 |
| Dec | 9 | 0 |

In summary, the R384 sample is made up of the following random weather observations:

| Region | Number of Obs. | Latitude | Longitude | Code |
|---|---|---|---|---|
| Gulf of Finland | 72 | 59-60 N | 22-29 E | L14 |
| Weather Ship J | 24 | 52-54 N | 18-21 W | WSJ |
| Yellow Sea | 77 | 31-33 N | 122-124 E | L8 |
| East China Sea | 19 | 24-26 N | 124-126 E | L4 |
| Gulf of Oman | 96 | 20-24 N | 58-59 E | IN5 |
| Caribbean | 96 | 10-17 N | 76-81 W | L5&6 |

### Random 400 (R400) Weather Datafile

Background. NSWC code F44 has a "weather data base" consisting of surface ship weather observations and calculated IR parameters for approximately 10,000 separate observations (14 locations, 12 months, 60 observations per month). This data base was created by NSWC in the late 1970's using surface marine weather observations provided by the Naval Weather Service Detachment in Ashville, NC. The observations included in the data base cover the 10 year period from 1964 to 1973. This data base (or selected subsets) are used to provide statistical assessment of sensor performance in the marine environment.

R400 Sample. The "Random 400" sample was originally put together for the AN/SAR-8 program as a "world wide weather" data file. The size of this file was selected as a reasonable compromise between computer run time and statistical accuracy. Locations were chosen to represent both areas where aerosol scattering is significant and areas where molecular absorption dominates. The sample is (approximately) uniform with respect to time of day and time of year, and includes observations from the following geographic locations:

50 observations from North Atlantic Weather Ship M located in the Norwegian Sea (65-67 N, 0-4E)

100 observations from North Atlantic Weather Ship J located approximately 450 miles west of Ireland (52.3-54.3 N, 17.8-20.8 W)

100 observations from two locations in the Eastern and Western ends of the Mediterranean Sea (32-35 N, 33-37 E and 36-37 N, 0-1 E)

50 observations from a location in the mid Arabian Sea (12-18 N, 64-69 E)

100 observations from two locations in the Flores Sea and Coral Sea near Indonesia (6-9 S, 116-120 E and 6-10 S, 153-156 E)

Figure D-1 is computed from Hepfer's data (collection R400 sorted into 10 degree latitude bins of calculated values using data on wind and wave, etc., to calculate the aerosols) using the Navy model.

Other collections have produced data in the very recent past. These and related articles also show that there is a very wide variation in the type and frequency of aerosols. These are shown for a single wavelength in Section IV where Gathman points out that the histogram of extinctions collected in MAPTIP during days 298-307 shows extinctions that are higher than those for days 291-297 by more than an order of magnitude, and the range of these larger extinction values occurs over a broader range of extinctions and occurs for a larger fraction of measured samples (Figure 4-8).

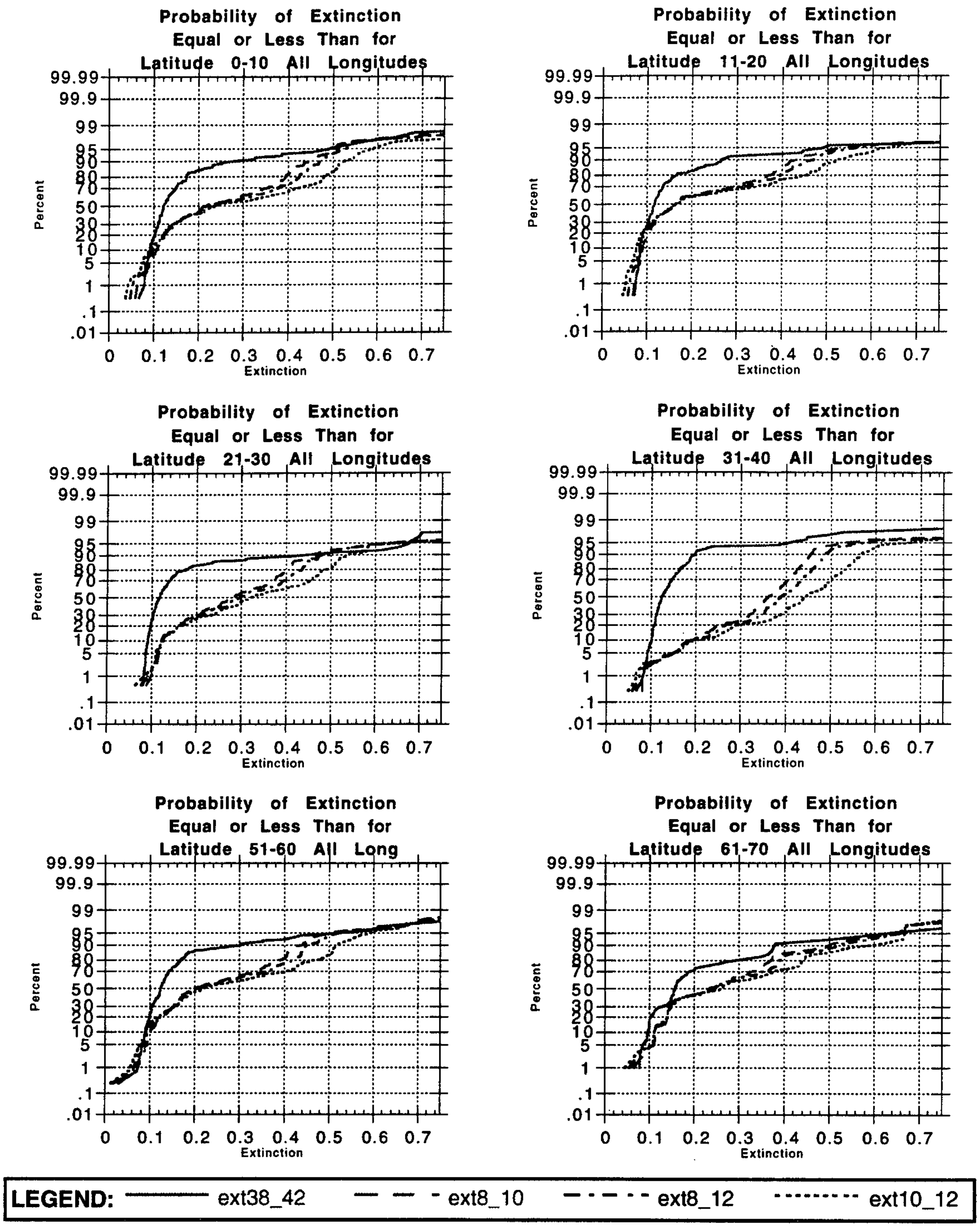



**Figure D-1. Probability of Extinction Equal to or Less than the Values Shown in the Abscissa for Latitudes 0-70, All Longitudes (from calculations based upon Hepfer, NSWC, Dahlgren, meteorological data collection)**

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**
March 1996

**3. REPORT TYPE AND DATES COVERED**
Final—January–December 1995

**4. TITLE AND SUBTITLE**
Infrared System Performance, Atmospheric Transmission, and Modeling Errors

**5. FUNDING NUMBERS**
DASW01 94 C 0054
ARPA Assignment A-180

**6. AUTHOR(S)**
Lucien M. Biberman

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Institute for Defense Analyses
1801 N. Beauregard St.
Alexandria, VA 22311–1772

**8. PERFORMING ORGANIZATION REPORT NUMBER**
IDA Paper P-3046

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Defense Advanced Research ProjectsAgency
3701 N. Fairfax Street
Arlington, Virginia 22203-1714

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution unlimited.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 180 words)*

This paper focuses on atmospheric transmission and its effect on the performance of an infrared sensor at a given location, season, and time of day. Atmospheric transmission is often simply taken to be the value defined by a season, a geographic location, and an altitude. In fact, the character of the atmosphere changes, often rapidly, affecting transmission. The characteristics of airborne targets are so different from those of shipping or most terrain based targets that the target often, if not always, dominates the choice of the spectral band to be used. The large variability in weather, and thus atmospheric properties, combined with the large range in target characteristics, combine to produce a very complex and not readily understood situation. For a tolerable range of extinctions, the choice of a band between 3 and 5 micrometers for airborne targets with prominent plumes appears more useful more of the time than the band between 8 and 10 micrometers. For the longer wavelengths, the *absolute* humidity is the serious factor, while for the shorter wavelength the relative humidity is the critical factor. These factors indicate the potential desirability of dual band systems.

**14. SUBJECT TERMS**
Infrared, Sensor, Atmosphere, Transmission, Utility

**15. NUMBER OF PAGES**
64

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | SAR |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102